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Ocean Incineration:

Its Role in Managing Hazardous Waste

CONGRESS OF THE UNITED STATES
Office of Technology Assessment
Washington, D. C. 20510

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Foreword

The American approach to managing hazardous wastes is undergoing rapid change. A decade ago Congress passed the Resource Conservation and Recovery Act (RCRA), formally recognizing the costs of past, indiscriminate land disposal. The Nation now is moving with some urgency toward development and greater utilization of methods that destroy, treat, recycle, or reduce the generation of hazardous wastes.

Within this context of change, one of the many distinct technologies for managing hazardous wastes—ocean incineration—has received an extraordinary degree of attention. Is ocean incineration part of the solution to, or simply a repetition of, the mistakes of the past? By burning hazardous wastes far from land, are we reducing risks to human health or simply shipping our problems out to sea? Is the small but real risk of a catastrophic spill worth the benefit of actually destroying most of the wastes? These and other questions have been the focus of considerable public attention over the last several years, and various congressional committees have responded by holding half a dozen hearings since 1983.

In 1984, two congressional committees—the House Committees on Merchant Marine and Fisheries and on Public Works and Transportation—requested the Office of Technology Assessment to undertake a broad study of wastes in marine environments, including an examination of ocean incineration. At that time, the Senate Committee on Commerce, Science, and Transportation endorsed the study. More recently, the original requesting committees and the House Committee on Science and Technology asked OTA to prepare a full report on ocean incineration. In response to the latter request, this assessment, *Ocean Incineration: Its Role in Managing Hazardous Waste,* provides a comprehensive examination of ocean incineration technology. A second assessment responding to the initial request is in preparation.

This assessment of ocean incineration includes consideration of the adequacy of regulations; risks to human health and the marine environment relative to the risks of comparable activities; existing and emerging alternatives; the capabilities and limitations of ocean incineration in managing hazardous wastes; and how its use might affect efforts to develop superior waste treatment and reduction practices. Particular attention is addressed to areas of intense public concern over the use of this technology. This report is offered to aid Congress in its deliberation of the fate and design of the ocean incineration program.

Many individuals in government, industry, the public interest and environmental communities, and academia contributed to the effort represented by this report. In particular, OTA wishes to thank the advisory panel and the many reviewers who devoted time and energy to this undertaking. Their involvement does not necessarily indicate endorsement of the report or agreement with its findings: OTA bears sole responsibility.

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Related OTA Reports

- *Wastes in Marine Environments.* In preparation.
- *Serious Reduction of Hazardous Waste for Pollution Prevention and Industrial Efficiency. In press.*
- *Transportation of Hazardous Materials.* OTA-SET-304; July 1986. GPO stock #052-003-01042-9; $13.00.
- *Superfund Strategy.* OTA-ITE-252; April 1985. GPO stock #052-003-00994-3; $10.00.
- *Protecting the Nation's Groundwater From Contamination.* OTA-O-233; October 1984. GPO stock #052-003-00966-8; $7.50.
- *Acid Rain and Transported Air Pollutants: Implications for Public Policy.* OTA-O-204; June 1984. GPO stock #052-003-00956-1; $9.50
- *Technologies and Management Strategies for Hazardous Waste Control.* OTA-M-196; March 1983. NTIS order #PB 83-189 241.

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Chapter 1

Findings and Policy Options

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Chapter 1

Findings and Policy Options

OVERVIEW

Few practices, even in the tumultuous arena of hazardous waste management, have engendered as much controversy and polarization as has the concept of burning hazardous wastes in incinerators mounted on ocean-going vessels. Critics have characterized ocean incineration vessels as "outmoded, unforgiving technology" and "nothing more than old-fashioned pot-bellied stoves without the smokestack," whereas proponents see ocean incineration as "a way to prevent the cancer that chemicals may cause" and "to destroy hazardous wastes before they destroy us." When the U.S. Environmental Protection Agency (EPA) held a public hearing on ocean incineration in Brownsville, Texas, in 1983, more than 6,000 people attended, which vividly demonstrates the level of public concern over this technology.[1] Such concerns have temporarily halted the development of ocean incineration in this country.

The debate over ocean incineration reflects the tenor of change taking place in the American approach to managing hazardous waste. The Hazardous and Solid Waste Amendments of 1984,[2] which amended the Resource Conservation and Recovery Act (RCRA), responded to the growing recognition that the methods used in the past to dispose of hazardous wastes should no longer be used. Mounting evidence of groundwater contamination and other problems associated with leakage of wastes from the growing list of Superfund sites lent a new sense of urgency to finding new approaches. To replace the old practices, Congress has called for the development of environmentally sound methods for disposing of, treating, destroying, and recycling hazardous wastes, and for reducing their generation. It is against this background of transition that Congress must decide what role, if any, ocean incineration should play in managing America's hazardous wastes.

Existing and developing methods for managing hazardous wastes are commonly organized into a hierarchy that accords preferred status to methods that reduce *risk* by reducing the quantity and degree of hazard of wastes.

The highest tier in the hierarchy includes those methods—collectively referred to as waste reduction—that actually avoid the generation of wastes.[3] Disposal practices that attempt to contain waste or actually disperse them in the environment occupy the lowest tier. Between these tiers are those methods—distinct from disposal practices—that reduce risks by recovering, treating, or destroying wastes after they are generated. For example, a properly operating incinerator can destroy more than 99 percent of certain hazardous wastes, greatly reducing both their quantity and degree of hazard.[4]

In such a hierarchy, the technology of ocean incineration falls midway between most disposal practices, which are generally inferior, and most reduction, recycling, and advanced treatment technologies, which are generally superior. For what hazardous wastes could ocean incineration be used? Of all hazardous wastes, only a fraction (up to 20 percent) is amenable to incineration. Of these *incinerable* wastes, only those in *liquid* form (up to about 8 percent of all hazardous wastes) could be incinerated at sea. For liquid wastes that are *highly chlorinated,* several technical factors partially constrain the ability of available land-based alternatives to effectively manage such wastes. Because these limitations do not apply to ocean incineration, it is one of only a few technologies available to manage highly chlorinated wastes.

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[1] This public hearing was the largest in EPA's history. At issue was whether to grant a permit for incinerating PCB- and DDT-containing wastes at an ocean site in the Gulf of Mexico.

[2] Referred to throughout this report as the 1984 RCRA Amendments (13).

[3] Not all practices that are commonly considered waste reduction actually lead to *risk* reduction. For example, process modifications can reduce the *quantity* of waste or alter its composition without necessarily reducing the *degree of hazard* of any resulting waste. As used in this report, however, the term waste reduction refers only to environmentally sound practices that actually accomplish *risk* reduction.

[4] The undestroyed fraction of the waste is released into the environment. Concerns about incineration generally focus to a greater degree on the magnitude and impact of these releases than on the magnitude and benefit of the destruction achieved.

The fundamental choice that must be faced is whether to develop an ocean incineration program. This decision must consider a variety of factors, both technical and nontechnical. Because no methods are risk-free, the risks that ocean incineration poses—to human health and the marine environment—and the benefits that it provides—by actually destroying most of the wastes—must be weighed against those of the land disposal practices and other treatment methods that are currently used for liquid incinerable wastes.

OTA finds that ocean incineration could be an attractive, though not essential, interim option for managing liquid incinerable wastes, in particular highly chlorinated wastes. Indeed, from several perspectives, the use of ocean incineration occupies a "middle ground." In a temporal sense, it is one of several options that could help bridge the gap between the practices of the past, which are being abandoned, and the preferred practices of the future (waste reduction, recovery, and recycling), whose capacity is only now developing. Several technical and economic factors would confine its applicability to a relatively small portion (less than 10 percent) of all hazardous wastes, although they are among the most toxic and concentrated of such wastes. Finally, with respect to both risks and benefits, ocean incineration falls midway between past and developing practices. For these reasons, ocean incineration could be a useful option today but is clearly not a panacea. Multiple waste management options must be developed if the Nation's hazardous waste problems are to be solved.

One of the major public concerns voiced over ocean incineration is that a need for the technology has not been demonstrated. Although it could play a role in meeting the expected near-term demand for alternatives to land disposal, OTA finds that an **absolute need** for ocean incineration cannot be analytically demonstrated for a number of reasons. The Nation *could* continue to rely on methods that are gennerally less tractable for such wastes. Moreover, predicting the rate at which preferred waste management practices will supplant the need for destruction methods such as ocean incineration is exceedingly difficult. (A *legal* requirement to demonstrate a need for ocean dumping—including ocean incineration—is contained in domestic and international regulations. No consensus exists, however, as to how this requirement should be interpreted and specifically applied to ocean incineration.)

OTA expects that ocean incineration would in general have only a limited effect on incentives for implementing preferred waste management practices. **Nevertheless, to ensure that the shift toward use of preferred practices is not impeded, any program for ocean incineration should be regarded as interim.** It is important to ensure that, if permitted, reliance on ocean incineration can be lessened as we develop greater capacity in better waste management practices and reduce the generation of hazardous wastes. Within this context, ocean incineration could provide an attractive option for interim management of *certain* wastes.

The Role of Congress

Despite its major involvement in shaping hazardous waste management policy, Congress has never directly addressed the issue of what role, if any, ocean incineration should play. As a result, the Federal Government's regulation of ocean incineration has evolved without any explicit indication of congressional intent. Although few hazardous waste management technologies have required direct congressional consideration, several special features of ocean incineration may necessitate that Congress examine public policy regarding this technology.

First, despite the fact that ocean incineration is used to destroy hazardous wastes, in many respects it falls outside of the policy and regulatory framework that Congress created, a framework that seeks to establish "cradle-to-grave" management of hazardous wastes. Because it takes place at sea rather than on land, ocean incineration has been placed into a different regulatory arena—under the umbrella of ocean dumping. The factors that originally motivated the regulation of ocean dumping, however, are somewhat at odds with the technology of ocean incineration, which involves wastes that cannot be directly dumped under present policy. Moreover, the intent of using this technology is to de-

Box A.—What Is Ocean Incineration?

The use of ocean incineration is both a relatively new and a relatively old phenomenon. Its use in Europe dates back to 1969 and has involved a total of six different vessels and hundreds of burns in the North Sea. Although the first U.S. research burn occurred in the Gulf of Mexico in 1974, ocean incineration has never been used on a routine commercial basis in the United States.

Incineration—whether on land or at sea—is intended to *destroy* wastes. The concept of ocean incineration combines the existing technologies of marine commerce in transporting hazardous chemicals and land-based incineration of hazardous wastes. The result is a tank ship capable of both transporting and burning hazardous wastes (see figure on next page). The ship is designed to operate at a site far removed from human populations and vulnerable freshwater sources. Indeed, ocean incineration was originally developed to replace dumping of toxic chlorinated wastes directly into the ocean, a widespread practice at the time, and to solve several problems (both environmental and economic) associated with burning such wastes on land.[5]

Ocean-Incinerable Wastes

Wastes suitable for ocean incineration are largely limited to liquid wastes with low metal content and with sufficient organic content to sustain combustion.[6] Such liquids comprise less than 10 percent of all hazardous wastes (see ch. 3). A portion of these wastes is burned in land-based incinerators and, in some cases, in industrial boilers and furnaces.[7] Significant quantities of some of these wastes are currently recovered for reuse. Many of these wastes have relatively high energy content and are in demand for their fuel value; others must be supplemented with auxiliary fuel or high-energy waste to ensure full destruction.

Ocean-incinerable wastes fall into several major categories, including waste oils, chlorinated and non-chlorinated solvents, and other organic liquids. In addition, special wastes such as polychlorinated biphenyls (PCBs) have been or are proposed to be burned at sea. Most liquid incinerable wastes are generated in coastal States, near major ports (see ch. 3). Almost all incinerable waste is subject to regulation under RCRA as hazardous waste.

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[5] The incineration of chlorinated (i.e., chlorine-containing) wastes generates a toxic and corrosive acidic gas, hydrogen chloride. On land, the gas must be neutralized through an expensive and difficult process, which itself generates a hazardous waste requiring disposal. At sea, the acid gas is neutralized by contact with seawater, which has a naturally high buffering capacity. Ocean incineration thereby avoids the problems encountered on land, but raises new environmental concerns. This topic is discussed in detail in chs. 2 and 8.

[6] Certain solid or sludge wastes that can be suspended in liquid waste to render them "pumpable" could also be incinerated at sea. Some land-based incinerators, including the type employed by most large commercial facilities, can burn a wide range of wastes, including organic solids and sludges, as well as liquids. See ch. 3.

[7] Destroying hazardous wastes in boilers and furnaces is a common practice only beginning to be regulated; under current regulations (46 FR 7666, Jan. 23, 1981), this practice is distinguished from incineration because the wastes are burned in the boilers and furnaces for the *primary* purpose of recovering the energy content of the wastes, not for thermal destruction. EPA estimates that in 1981 almost twice as much hazardous waste was burned in boilers and furnaces as was burned in incinerators (8). Also see ch. 4.

stroy wastes to the extent possible, in order to avoid the need for direct dumping (on land or at sea).[8]

Second, because of its nature and setting, ocean incineration entails a wide variety of activities that are regulated under numerous Federal statutes and agencies. These include:

- land transportation of hazardous material by truck or rail;
- use and development of port facilities;
- federally regulated activity in States' coastal zones;
- marine transportation of hazardous material;
- transportation, storage, treatment, and disposal of hazardous waste;
- activities that can result in air or water pollution; and
- activities that can affect endangered species.

Third, the activities and possible consequences of ocean incineration typically cross political boundaries to encompass multiple State and municipal jurisdictions. The use of ocean incineration can take

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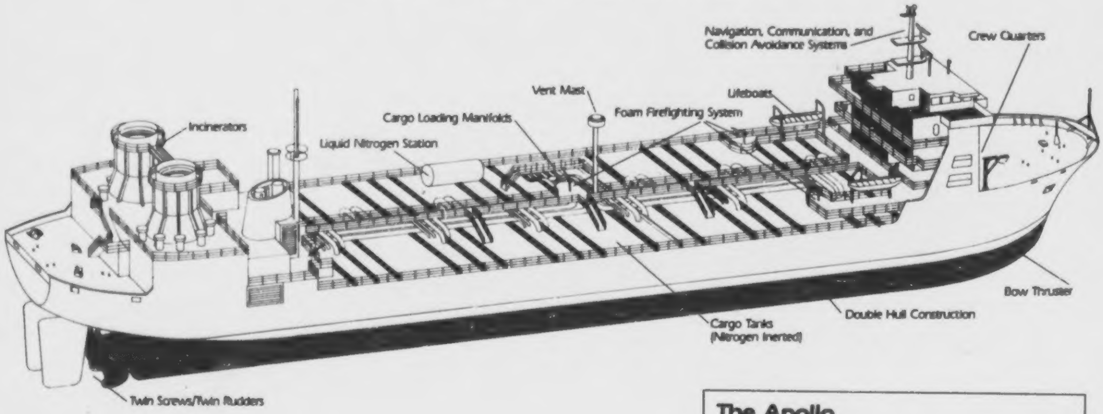
[8] To a significant degree, this intent is accomplished; however, those wastes that are not destroyed are released directly into the marine environment.

Design of an Ocean Incineration Vessel



The Apollo

Overall length	369 feet
Beam	60 feet
Gross tonnage	4,850 tons
Liquid cargo capacity	1.33 million gallons
Number of cargo tanks	12
Sustained sea speed	10.7 knots
Range with full load	6,940 nautical miles

SOURCE: At-Sea Incineration, Inc.

on international dimensions as well: waste or waste products released into the environment by ocean incineration may travel significant distances, and the site in the Gulf of Mexico designated by the United States is near the waters of other nations. Moreover, the potential for U.S. actions to set precedents for other nations must be considered.

Fourth, the level of controversy and significant public involvement in the debate over ocean incineration may warrant congressional attention. Although the initial public response often centered on local or regional concerns, the debate has become national in scope. As a result, ocean incineration is increasingly viewed in a broad context, as only one component in the process of shaping a national strategy for managing hazardous wastes.

These factors are not unique to ocean incineration, but their sheer number and systematic involvement in every application of this technology indicate a special need for an explicit policy toward ocean incineration, clearly defining what role, if any, the technology should play in managing hazardous wastes.

Congressional involvement in decisions regarding ocean incineration could take any of several forms. The fundamental decision of whether and, if so, how to proceed with ocean incineration requires consideration of numerous different technical and nontechnical factors. Many of these are regulatory in nature, but may require oversight or direction from Congress. However, other aspects of ocean incineration identified throughout this report raise questions regarding the adequacy and appropriateness of the current statutory authority for regulating ocean incineration. The inclusion of ocean incineration under the rubric of ocean dumping and the lack of statutory authority to develop comprehensive regulations governing ocean incineration are two examples of such issues. If ocean incineration is permitted, resolution of these questions may necessitate clarifying legislative action on the part of Congress.

Finally, Congress could take specific action to decide the *fate* of the ocean incineration program. Such action would directly establish national policy toward use of this technology, and could help guide EPA and the public in determining whether and how ocean incineration should fit into the Nation's hazardous waste management strategy. In the absence of such action on the part of Congress, the ultimate fate of ocean incineration in the United States is an open question.

Major Public Concerns

Despite the routine use of ocean incineration for more than 15 years in Europe and more than a decade of trial experience in the United States, a regulatory program for ocean incineration has not yet been implemented.[9] Indeed, commercial ocean incineration, which has occurred only sporadically in this country, has been delayed at least temporarily, pending (at a minimum) final regulations and one or more research burns. A primary reason for the Nation's hesitance to embrace ocean incineration as a hazardous waste management technology has been the strong public opposition to it. The opposition reflects a broad spectrum of concerns, some specific to ocean incineration itself, and others symptomatic of the much larger problem of hazardous waste management in general.[10] These concerns, which are evaluated in greater depth throughout this report, include the following questions:

- whether EPA has fully considered both existing and developing alternatives to ocean incineration;
- whether ocean incineration is needed, in light of the available alternatives;
- whether the risks and consequences of spills on land or at sea resulting from transporting or handling of waste are sufficiently understood, and in particular, whether available means of responding to a spill are adequate;
- whether shipboard incinerators can adequately destroy wastes without posing unacceptable risks to the marine environment or to humans;
- whether the regulations, monitoring, and enforcement provisions proposed by EPA are sufficient to govern all phases of ocean incineration activities; and
- whether sufficient research has been conducted to justify the use of ocean incineration, given our level of understanding of the marine environment and the value of its resources.

In addition, the following areas of need have been identified in the public debate over ocean incineration:

- the need to develop an overall hazardous waste management strategy that would place greater emphasis on reducing wastes at their source and would clarify the role, if any, of ocean incineration in such a strategy;
- the need for adequate measures to ensure that users of ocean incineration are fully liable for environmental releases or damages resulting from ocean incineration, and, in particular, the need for measures to address the claims of injured parties in such cases; and
- the need to consider the integrity and past records of applicants for ocean incineration permits.

In addition to these and other specific issues, an overriding area of public concern is whether EPA can regulate ocean incineration in an effective and objective manner and be truly responsive to the public. The lack of public trust in EPA has its roots in the somewhat thorny history of U.S. involvement with ocean incineration, which is perhaps best illustrated by examining the **provisional** nature of the current regulatory program.[11]

With regard to ocean incineration, the U.S. Government has undertaken three very different activities: research, regulation, and promotion. The relationships and boundaries between these activities have often been ill-defined, and EPA has not always fully appreciated the potential for conflicts of interest, or even the appearance of conflicts of interest. As a result, several such conflicts have arisen, three of which are discussed below:

1. EPA has never clearly communicated when and in what sequence it would conduct its ocean incineration research and develop its regulations. Consequently, questions have

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[9] EPA proposed regulations for ocean incineration in February 1985 (50 FR 8222, Feb. 28, 1985). For the purposes of this report, this Ocean Incineration Regulation will be used to represent EPA's current approach to regulating ocean incineration, although numerous changes are expected in the final regulation.

[10] A thorough and thoughtful discussion of the major areas of public concern is contained in the recent Hearing Officer's Report on the Tentative Determination to Issue the Incineration-at-Sea Research Permit HQ-85-001 (20), issued by EPA on May 1, 1986, and in the Summary of Public Comments accompanying that report.

[11] This issue was first clearly identified in the Hearing Officer's Report (20) on EPA's proposed research burn; several additional provisional elements bearing on ocean incineration in general are listed here, drawn from the history of government involvement in this area.

arisen as to whether the results of research burns carried out under the research strategy would be part of the data on which regulations would be based or whether EPA intended to develop and issue regulations before granting any permits (research or otherwise). Such unanswered questions have made the entire process appear haphazard.[12]

2. The government's promotional role culminated in the U.S. Maritime Administration granting a guaranteed loan to finance the construction of two incineration vessels by a private company.[13] Although the government's promotion of ocean incineration may well have been based on a genuine belief that the technology was both needed and environmentally sound, many members of the public have questioned the wisdom of promoting the technology before developing a regulatory program. In the eyes of its critics, EPA has compromised its ability to fairly assess the merits and risks of ocean incineration.
3. EPA proposed to conduct its research burn in the North Atlantic Ocean at a site that has not been formally designated, and the Agency has yielded to other agencies the authority to regulate several important activities related to ocean incineration. Although clearly allowed or even required under existing regulations and statutes, such an approach makes the regulatory program seem tentative and fragmentary.

Many of the public concerns about ocean incineration can be addressed through technical or regulatory means, but the lack of credibility and public trust are, in many respects, far more difficult to overcome. If ocean incineration is to play a role in hazardous waste management, the government must not only address the specific issues listed above, but must also provide for meaningful public involvement in the decisionmaking process in a manner that restores public confidence.

Evaluating Ocean Incineration in a Broad Context

As the previous discussion suggests, developing a policy for ocean incineration will require Congress to reexamine its policy towards the management of hazardous wastes as a whole. Legitimate concerns have been raised over the need for ocean incineration, the risks it poses to the environment, and the numerous unresolved questions and uncertainties regarding its use. These concerns are best viewed in the context of the corresponding availability, risks, and unknowns associated with alternative methods for managing incinerable waste. This is true for at least two reasons: no methods are free of risk and uncertainty, and a decision not to employ one method necessarily results in the use of other methods.

Thus, resolution of the debate over ocean incineration will require a thorough and objective *comparative* assessment of the technology. In particular, the full range of available choices and the tradeoffs they entail must be clearly communicated.

In developing the analysis presented in this report, OTA encountered many issues whose dimensions extend well beyond the confines of ocean incineration, and often beyond those of hazardous waste management in general. Some of these issues include:

- the possibility that allowing the use of existing treatment and disposal methods would serve as a disincentive for developing and using better methods;
- the risks and regulation of hazardous materials transportation;
- problems with regulatory enforcement;
- the government's capacity to monitor for adverse environmental impacts;
- the complexity of the hazardous waste market and its response to changes in the regulatory or economic climate;
- the adequacy of liability provisions applicable to hazardous waste management;

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[12] EPA recently decided (51 FR 20344, June 4, 1986) to deny a proposed permit application for a research burn that the Agency had earlier solicited to serve as one component of its Ocean Incineration Research Strategy (16). In the decision, EPA stated that no permits, research or otherwise, will be granted until final regulations are promulgated. Although this statement clarifies current EPA policy, it raises questions about how the regulatory development process will be affected by the absence of information from the research burn that was intended to aid in that process.

[13] The company, Tacoma Boatbuilding, Inc., recently filed bankruptcy proceedings, and its subsidiary, At-Sea Incineration, Inc., was forced to default on its loan payments, due in large part to its inability to obtain operating permits for the vessels.

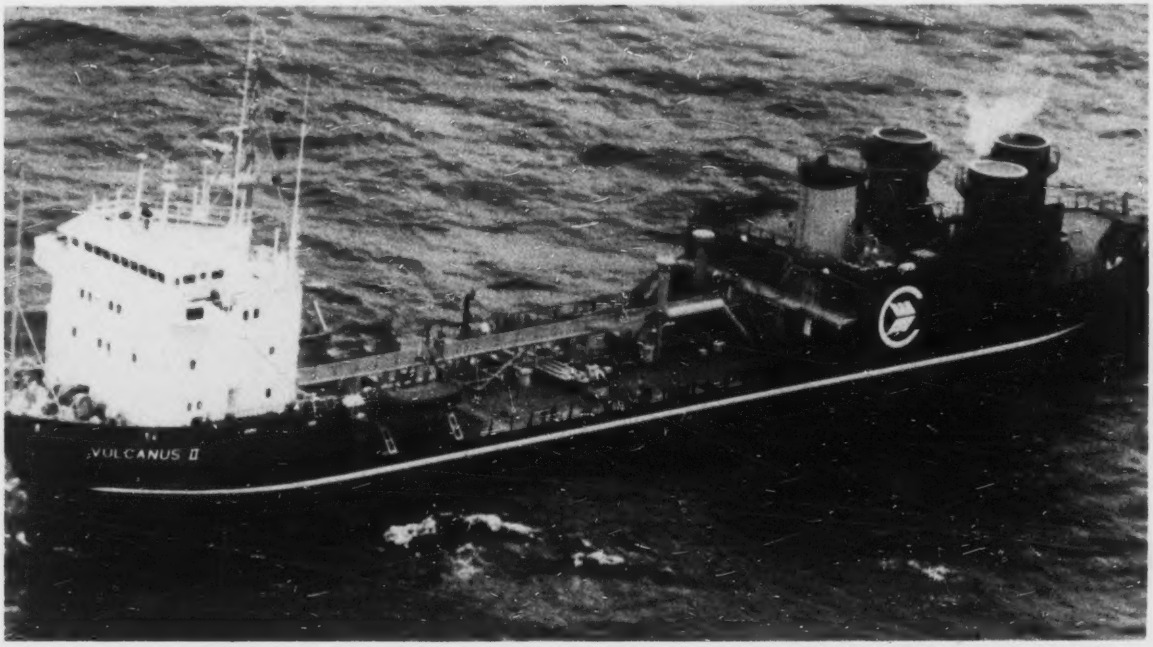

Photo credit: Chemical Waste Management, Inc.

The *Vulcanus II* incinerator ship.

- the difficulties associated with the siting of hazardous waste management facilities; and
- the need to develop appropriate means of involving the public in the decisionmaking process.

This report identifies and addresses many of these issues within the limited context of ocean incineration. In particular, the report explores those aspects of each issue that are unique to ocean incineration, or for which specific approaches can be offered for their resolution. Wherever possible, concerns regarding ocean incineration are considered in context by comparison to concerns associated with related or comparable activities.

MAJOR FINDINGS

The Potential Role of Land-Based and Ocean Incineration[14]

As much as 10 to 20 percent of the estimated 250 million metric tons of hazardous wastes generated in the United States each year *could in theory be* incinerated. Nearly half of all incinerable wastes (up to about 8 percent of all hazardous wastes) are liquids that could be incinerated at sea. Currently, however, only about 1 percent of hazardous waste is actually incinerated, and all of the incineration occurs in land-based facilities.

A broad range of practices is used for managing incinerable hazardous wastes today. Significant quantities of such wastes (as much as one-third) are recovered or recycled. Even larger quantities (as much as 65 percent), however, are being disposed of on land (in underground injection wells, landfills, or surface impound-

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[14] These findings are drawn from material presented throughout the body of the report. Wherever appropriate, chapters containing a full discussion of the basis of these findings have been indicated and should be consulted.

ments) or burned as fuel in boilers and furnaces.[15]

Although a number of innovative treatment technologies now under development will ultimately be preferable to incineration, **today's land-based and ocean incineration technologies represent a significant improvement over land disposal of incinerable wastes.** A properly operating incinerator can permanently destroy 99.99 percent or more of such wastes, in marked contrast to land disposal, in which wastes remain hazardous for long periods of time.

Numerous studies have examined future demand for incineration capacity *in general*. Surveys conducted by both private and governmental organizations (including EPA, the Congressional Budget Office, numerous State and regional hazardous waste management planning commissions, and several waste generating industries) predict that **this demand will continue to grow into the foreseeable future.** Projections indicate that increased quantities of hazardous waste will be generated and will be managed through incineration. For example, current regulations mandate that waste containing high concentrations of polychlorinated biphenyls be incinerated (see box B in ch. 3). In addition, if implemented even roughly on schedule, the 1984 RCRA Amendments will restrict the land-based alternatives traditionally used for disposing of incinerable wastes and are expected to substantially increase the amount of waste available for incineration (see ch. 3).

Despite this expected demand, existing incineration capacity is significantly below what would be needed to burn all incinerable wastes. Moreover, this shortfall is likely to increase with time, largely as a result of two factors: first, the increase in demand described above; and second, the very slow development of new capacity. Indeed, efforts to increase incineration capacity have encountered many obstacles, including public opposition, limited availability of liability insurance, and difficulties in facility siting.

Despite this shortfall, a future *need* for ocean incineration (or land-based incineration, or any other hazardous waste management technology) may never be demonstrated or quantified from an *analytic* standpoint. (See ch. 2 for a discussion of the legal requirement to demonstrate a *need* to incinerate at sea.) The regulatory status, economic attractiveness, capacity, and actual use of each technology for managing incinerable waste vary widely, change with time, and are exceedingly difficult to predict. It is the complex interaction of these factors that determines the market or need for any individual option. **Thus, although establishing or estimating a specific need for ocean incineration is virtually impossible, a need clearly exists for having available a number of technologies capable of managing incinerable wastes.**

For highly chlorinated wastes, ocean incineration may be preferable to available alternatives, with respect to human health risks and cost-effectiveness (see section below on technological limitations).

For other wastes, certain existing technologies may offer economic or environmental advantages over both land disposal and incineration. Current competing alternatives such as industrial boilers and furnaces burn wastes with high heat content to recover energy; these practices, however, are currently subject to significantly less regulatory control than is incineration and may, in some cases, pose significant environmental or human health risks. Other alternatives allow the recovery of materials from the waste. Solvent distillation, oil reclamation, chlorination processes, and hydrogen chloride recovery are examples of this approach. The use of such technologies for managing hazardous wastes, including developing a proper regulatory framework, should be explored further.

Certain emerging waste reduction and treatment options will ultimately prove to be an even greater improvement over the incineration technologies now available, although accurately estimating their near-term availability and capacity is not currently possible.[16] In any case, the need for waste treatment and disposal options will continue because of the sheer quantities of wastes, the time required to implement waste reduction measures and to develop sufficient capacity for recycling and advanced treatment, and the fact that not all wastes will lend themselves to such techniques.

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[15] See footnote 7 in box A.

[16] See ch. 4 for a brief discussion of these emerging methods. Another OTA assessment (14) is examining the potential for reducing the generation of industrial wastes.

For a fuller discussion of the potential role of land-based and ocean incineration, see chapters 3 and 5.

Comparison of Land-Based and Ocean Incineration

If additional capacity to incinerate liquid wastes is developed, the choice between expanding land-based incineration or developing ocean incineration cannot currently be resolved on a technical basis. Nor will the collection of more information be likely to significantly aid in answering this question. When specific technical factors are analyzed one at a time, one technology may seem clearly preferable to the other, but when all such factors are considered as a whole, the analysis does not lead to an unambiguous choice. Several areas of comparison between land and ocean incineration are particularly important to consider.

Regulation

In general, the proposed regulatory framework for ocean incineration is more stringent and explicit than the existing regulations that govern land-based incineration. Technical limitations and performance standards, as well as requirements for obtaining permits, monitoring, and reporting, tend to be more involved and leave less to the judgment of those issuing permits for ocean incineration.

In part, the regulatory differences reflect the fact that the two technologies are addressed under different primary statutes. However, they also appear to reflect two other factors: heightened public concern over ocean incineration, and greater perceived and actual difficulties in monitoring an activity that takes place far from shore.

For a fuller discussion of regulation, see chapter 7.

Releases of Waste

Releases of waste from the actual incineration process should be equivalent for land-based and ocean incineration, although the nature and location of these releases could differ substantially. Because ocean incineration requires additional transportation and handling of hazardous wastes, however, it is likely to result in a somewhat greater release of waste to the environment than would land-based incineration.

EPA proposes that incineration vessels not be required to have air pollution control equipment, which is required on some, but not all, land-based incinerators.[17] This factor would not alter the total quantity of waste products released during the actual incineration process. The quantity of such products *directly released through the stack* would be greater for ocean incineration than for land-based incinerators equipped with scrubbers. However, operating a scrubber generates a hazardous waste containing pollutants that would otherwise have been emitted; this waste must be disposed of and may itself be released to the environment, with potential to contaminate groundwater or surface water.

The *size* of a release is only one factor that influences the severity of impact. The nature and location of expected releases must also be considered. Land-based and ocean incineration differ significantly with respect to these factors. See chapter 8 for a fuller discussion of waste releases from land-based and ocean incineration.

The Issue of Scrubbers

The major technological and regulatory difference between land-based and ocean incineration is the absence of scrubbers on ocean incineration vessels. Scrubbers are present on approximately 45 percent of existing land-based incinerators (see ch. 5), including all of the large commercial facilities that would offer the most direct competition to ocean incineration.

The debate over the need for scrubbers on incineration vessels has been clouded by two common misperceptions regarding scrubber and incinerator performance. The first involves the issue of which particular waste products are actually removed by scrubbers. Scrubbers are generally very effective at removing acid gases (e.g., hydrogen chloride) and particulate emissions (which include a large portion of toxic metals), but are *not* effective at removing residual organic material—unburned wastes or products of incomplete combustion (refs. 11,17; also see ch. 7).

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[17] For convenience, such equipment will be referred to in general as "scrubbers." Land-based incinerators burning chlorinated liquid wastes or solid wastes generally possess scrubbers, as do the large land-based *commercial* incinerators. Other land-based incinerators that burn other types of liquid wastes often do not; use of these facilities generates emissions equivalent to incinerators at sea burning the same waste. This issue is discussed at greater length in the next section on scrubbers, and in chs. 2 and 7.

A second misperception is that a difference exists between the emissions of organic material that are allowed for land-based and ocean incineration. The performance of ocean incinerators (as well as land-based incinerators lacking scrubbers) is to be measured by calculating a destruction efficiency (DE). The performance of land-based incinerators that carry scrubbers is measured by calculating a destruction *and removal* efficiency (DRE), after emissions have passed through the scrubber. The DE standard proposed for ocean incineration is identical to the DRE standard for land-based incinerators with scrubbers. Hence, emissions from ocean incinerators could not be any greater than those from land-based incinerators, even *after* accounting for any incidental removal of organic material accomplished by the scrubber. In other words, even if scrubbers were effective at removing organic material from stack gases, ocean incinerators would still be held to the *same* overall destruction performance standard.[18]

For these reasons, an evaluation of the need for scrubbers at sea should focus on hydrogen chloride and particulate emissions. For these pollutants, EPA's rationale for not requiring scrubbers on incineration vessels is that:

- hydrogen chloride gas emissions would be rapidly neutralized because of the high natural buffering capacity of the marine atmosphere and seawater, and
- particulate emissions would be minimal because of the specific limits placed on metal content of wastes to be incinerated at sea and the fact that incineration of liquid wastes generates fewer particulates than does incineration of solid or mixed wastes.

Hydrogen Chloride Gas Emissions.—A review of available data reveals little documentation for any significant adverse environmental impacts attributable to hydrogen chloride gas released from incineration vessels. Before 1979, incineration in the North Sea took place at a site only 23 miles off the Dutch coast. Although no causal link to ocean incineration was established, the presence of a slightly irritating acidic atmosphere along the coastline was reported and was one factor leading to the movement of the incineration site to a new area more than 60 miles from the nearest shore (4,21). Designated or proposed U.S. sites are 140 to 190 miles from the nearest shoreline.

Acid wastes of a much higher concentration than would be emitted through ocean incineration are directly dumped at two industrial waste disposal sites in the North Atlantic Ocean (3). Although this direct dumping has caused some short-term and localized perturbations in the alkalinity of the seawater, complete neutralization occurs within a few hours after the dumping and no adverse effects on marine life have been detected. In ocean incineration, the much lower concentrations of acid would be deposited over a larger area and over a longer period of time than is the case in direct dumping. Indeed, past monitoring of ocean trial burns did not detect any change in the alkalinity of surface waters that came into direct contact with the incinerator plume (see ch. 11). The potential for damage to occur to organisms in the surface microlayer prior to dispersion or neutralization, however, has not been adequately addressed (see ch. 9).

EPA has proposed an environmental performance standard that would allow only a very small change in the alkalinity of seawater at an incineration site. EPA's calculations indicate that this standard would easily be met even under extreme circumstances (see chs. 7 and 8).

According to the chairman of the committee that prepared the Science Advisory Board report on ocean incineration (19), these and other considerations led the SAB to conclude that using the buffering capacity of the ocean to neutralize acidic emissions from ocean incinerators did not pose any major problems (5).

Particulate Emissions.—Incinerating hazardous waste generates particulate matter that is composed primarily of metals, along with other inorganic material originally present in the waste. The chief motivation for controlling particulate emissions is that, in the process, a significant portion of toxic metals is also controlled.

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[18] Several shortcomings in the operational definitions of DE and DRE have been identified (see ch. 2). Because the shortcomings apply equally to land-based and ocean incineration, however, they do not aid in the comparative evaluation.

Toxic metals are "conservative" pollutants; that is, they are not destroyed in the environment or even in a process such as incineration, although their chemical form and degree of hazard can be altered. Thus, any toxic metals present in the original waste remain after incineration, either in the residual ash left in the combustion chamber or in the exhaust stream exiting the incinerator stack.

Two different approaches to controlling metal emissions have been applied to land-based and ocean incineration. On land, stack scrubbers are utilized to trap particulates, but relatively little control is exercised over the metal content of wastes to be incinerated. At sea, rather than require scrubbers, EPA has proposed to limit the metal content of wastes accepted for incineration. Emissions of some metals would be further limited by an environmental performance standard that would prohibit applicable marine water quality criteria to be exceeded (see ch. 7).

In addition to the amount of a metal present, its *chemical form* affects its behavior in the environment, its potential to cause adverse impact, and in some cases the efficiency with which it is removed by a scrubber (see ch. 7). The insufficient characterization of incinerator emissions described previously extends to determining the chemical form, as well as quantity, of particular metals. **It is essential that such a characterization be undertaken if the absence of a requirement for scrubbers on incineration vessels is to be justified.** Further regulation of metal emissions may well be warranted, given EPA's finding that most of the human health risks associated with ocean incineration are derived from metal emissions (18).

Determining the appropriate limits for metals in wastes to be incinerated at sea certainly requires further scrutiny, but in general EPA's proposed approach to limiting metal emissions is a reasonable alternative to requiring scrubbers on ocean incinerators. Such an approach, however, must be coupled with rigorous environmental monitoring to determine if unacceptable impacts occur.

As a final consideration, available data indicate that even under the most extreme circumstances allowed under EPA's proposed regulation, the total amount of metals released into the marine environment from ocean incineration would be very small in comparison to the amount from other sources and permitted activities (see ch. 8).

Therefore, **based on the available information, OTA finds that the lack of a requirement for air pollution control equipment on ocean incineration vessels appears justified, so long as operating conditions and the metal content of wastes incinerated at sea are appropriately regulated and such activity is linked to a rigorous environmental monitoring program.**

Two additional arguments have been offered against requiring air pollution control equipment on ocean incineration vessels. First, the costs of installing, maintaining, and operating such equipment are substantial, and could significantly reduce the competitive status of ocean incineration relative to other alternatives. Second, the installation of scrubbers on incineration vessels faces major design impediments, including spatial, weight, and fresh water requirements (15). Such constraints are especially applicable to retrofitting existing ships, which have short vertical stacks. (Other proposed designs would utilize seawater "scrubbers" on horizontally oriented incinerators, but the scrubber effluent would be discharged directly into the ocean, making the term *scrubber* somewhat of a misnomer.)

Although further research into using true scrubbers aboard ships is certainly warranted, their immediate application appears difficult if not impossible. In their absence, EPA's reliance on an appropriate combination of waste and emissions limitations, incinerator performance standards, and environmental monitoring requirements appears to be a reasonable alternative approach.

Health and Environmental Risks

Land-based and ocean incineration each involve several kinds of risks, some of which are unique to one technology, others common to both. Their *primary* risks differ substantially, however, thus constraining any quantitative comparison of these technologies. Consideration of these primary risks is, nevertheless, essential in determining policy toward the use of incineration.

Because land-based incineration occurs relatively close to human populations, its primary risk is the potential for adverse impact on human health—resulting from exposure to routine or normal releases of waste or waste products. A full understanding of the magnitude of this risk is constrained by our lack of knowledge concerning the nature of incinerator emissions and the difficulties associated with environmental monitoring of land-based incinerators.

In contrast, ocean incineration's primary risk is to the marine environment. Most of this risk derives from the potential for a major accidental spill. By all estimates, such an event would be extremely unlikely to occur, even less likely than a spill resulting from the transportation of nonwaste hazardous materials. However, a major spill of either hazardous waste or nonwaste material could have catastrophic consequences; for example, if it occurred in a sensitive estuarine area, large-scale loss of fish and bottom-dwelling organisms could result. The situation would be exacerbated by the acknowledged difficulty or impossibility of cleanup.

The major risk to human health from ocean incineration is expected to arise from exposures due to the transport and handling of wastes on land. In this respect, land-based and ocean incineration appear to be quite similar.

For further discussion of risks to human and environmental health posed by land-based and ocean incineration, see chapter 9.

Unanswered Questions

EPA's Science Advisory Board has identified many unanswered questions, regarding performance and emissions, that apply to both land and ocean modes of incineration and, in some cases, to all combustion processes.[19] For example, the SAB stated that no reliable characterization of emissions or their toxicities is available for either technology, which means that the potential for exposure and adverse impact to the environment or to humans cannot be adequately assessed. The study also challenged EPA's method of evaluating the total performance of both land-based and ocean incinerators by measuring destruction efficiency for only a few selected compounds. The SAB recommended that EPA undertake a complete characterization of emissions and products of incomplete combustion arising from both technologies. These well-founded concerns are addressed in more detail in chapter 2.

Technological Limitations

Because land-based and ocean incineration each possess inherent capabilities and limitations, from a technical perspective **certain wastes are better managed by one or the other technology.** Two examples of such factors are discussed below.

First, **because they cannot incinerate solids and sludges, ocean incinerators are inherently less versatile than land-based rotary kiln incinerators, despite their greater capacity.** Such a limitation can be especially important in local or regional settings, where a variety of waste types may need to be incinerated. In addition, applying waste recovery and recycling technologies to incinerable wastes is expected to increase the amounts of incinerable solids and sludges at the expense of incinerable liquids (see ch. 3). For these and other reasons, a number of States[20] plan to build land-based rotary kiln facilities to meet their anticipated needs. It is not known how much and how soon such efforts might affect the shortfall between capacity and demand for incineration.

Second, despite the limitation discussed above, incineration of highly chlorinated wastes at sea has commonly been preferred over their incineration on land. Indeed, in both Europe and the United States, ocean incineration has been employed almost exclusively for highly chlorinated wastes. The extensive rationale for this is based on the fact that incinerating such wastes generates high concentrations of corrosive and toxic hydrogen chloride gas. For numerous reasons related to this finding, **incineration of highly chlorinated wastes at sea may be advantageous**:

- Incineration of such wastes on land requires the use of scrubbers, which are costly and difficult to operate and maintain.

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[19] Such processes include the burning of fossil fuels in powerplants, the burning of gasoline in automobiles, and even the burning of wood in fireplaces.

[20] For example, see refs. 2,7.

- Scrubber operation generates additional hazardous waste that must be disposed of, typically through neutralization and discharge into sewers or surface impoundments. These practices can in turn contaminate groundwater or surface water.
- Limitations on the chlorine content of waste are often written into the operating permits of land-based incinerators, for three reasons:
  - —Certain highly chlorinated wastes can, in fact, exceed the feasible capacity of scrubbers for removing hydrogen chloride gas.
  - —The energy content of a waste decreases as the chlorine content increases. Thus, for a given feed rate, as chlorine content increases a point is reached where insufficient energy is present to ensure combustion.
  - —Free chlorine gas, which is even more toxic to humans than hydrogen chloride gas and is *not* efficiently removed by scrubbers, is generated during the incineration of highly chlorinated wastes. As a result, an upper limit on the chlorine content of wastes must be set, usually at about 30 percent (23).

  In light of these factors, highly chlorinated wastes can be burned on land only if they are blended with auxiliary fuel or nonchlorinated wastes to reduce the chlorine content and increase the energy content of the waste being incinerated. The net effect is a reduction in the effective capacity of land-based incinerators for *chlorinated* wastes.
- Ocean incineration vessels are not required to have scrubbers, because of the capacity of seawater to neutralize hydrogen chloride gas, and because the incinerators operate at a location far removed from human populations. (See section above on scrubbers and chs. 2 and 7.)
- Because they lack scrubbers, ocean incinerators can burn chlorinated wastes at a much higher rate than can land-based incinerators. Consequently, ocean incineration has a greater capacity for chlorinated wastes. Moreover, the higher feed rate reduces or obviates the need to use supplementary fuel or high energy wastes.

Thus, from the perspectives of human health risks, capacity, and cost-effectiveness, incinerating highly chlorinated wastes at sea may be preferable to incinerating them on land. These benefits must be balanced against the potential risks ocean incineration poses to the marine environment.

Releases of Waste to the Marine Environment

Releases of waste and risks of impact from ocean incineration should properly be viewed in the context of releases and risks from comparable activities and from other sources of marine pollution. Only in such a context can the significance of such risks in relation to potential benefits be fully assessed.

Ocean incineration entails a very small incremental increase in risk relative to that routinely borne by this Nation in the marine transport of hazardous (nonwaste) materials. This is the case with respect to the number of transits, quantities and types[21] of material carried, and the expected frequency and size of releases. **However, given the potentially catastrophic consequences of a major marine spill, the acknowledged difficulty or impossibility of cleanup, and the intense public concern focused on this issue, extensive regulatory attention would be warranted if ocean incineration were permitted.** This should include consideration of measures beyond the already substantial provisions that exist or have been proposed by EPA and the U.S. Coast Guard (see ch. 2).

In certain settings, the normal operation of incineration vessels may represent a small but potentially significant contributor of some pollutants to the marine environment. **This contribution, however, is expected to be considerably smaller than that of other permitted activities that introduce pollutants to marine waters.** Furthermore, pollutants released during normal incineration operations would result in virtually no detectable long-term increase over background levels, except in extreme circumstances.

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[21] One major exception is special wastes, such as PCBs, which are no longer commercially produced and are therefore not routinely transported, except as waste. See box B in ch. 3.

Prior to dispersing, pollutants emitted by ocean incinerators could cause short-term adverse impacts upon contact between the incinerator plume and the ocean surface. Although the affected region is expected to be limited to a small area along the path of the ship, in this region significant damage could result. Further study of such impacts, particularly on the surface microlayer (see ch. 9), is warranted.

For further discussion of releases of waste from ocean incineration relative to other sources of marine pollution, see chapter 8.

Past and Current Use of Hazardous Waste Incineration

Currently, all U.S. incineration of hazardous wastes takes place in land-based facilities. EPA has estimated that there are currently 240 to 275 land-based hazardous waste incinerators in the United States (6,10). About 210 to 250 of these facilities are located at sites where the incinerated wastes are generated. These *onsite* facilities are generally used solely for incinerating wastes generated by their owners. Approximately 30 others are commercial, *offsite*, facilities used to incinerate waste generated by industrial clients. Estimates of the annual quantity of wastes destroyed by incineration range from about 1.7 million metric tons (mmt) in 1981 (22) to 2.7 mmt in 1983 (12). In 1980, about 0.4 mmt was incinerated at commercial facilities (1).

Ocean incineration has been employed in the United States only on a research or interim basis, but has been used routinely in the North Sea for European wastes for more than a decade. Two incinerator ships are currently operating in Europe;[22] two have recently been built in the United States, but have yet to be employed commercially. Several other companies have expressed interest in the market.

The technological performance and environmental effects of ocean incineration have been subjected to considerable testing (see ch. 11). Unfortunately, the results of this effort are hotly contested, and do not aid substantially in evaluating the safety of ocean incineration. The test data appear to support two somewhat conflicting findings:

1. Ocean incineration can, at least under certain conditions, meet applicable regulatory and technical requirements and achieve very efficient destruction of hazardous wastes.
2. The technology's ability to perform in such a manner consistently has not been demonstrated for complex mixtures of wastes or the broad range of operating and environmental conditions likely to be encountered.

For further discussion of the use of hazardous waste incineration at sea and on land, see chs. 3, 5, and 11.

Recovery, Recycling, and Reduction of Incinerable Wastes[23]

Recovery, recycling, and reduction practices are generally given preferred status in the hazardous waste management hierarchy discussed previously. Many critics of ocean incineration argue that allowing its development would impede efforts to implement these preferred practices. (In the following discussion, a distinction is drawn between waste *recycling/recovery* and waste *reduction*.)

Some wastestreams comprising incinerable waste are very amenable to recovery and recycling processes. Much of this potential, however, is already being realized. For example, large quantities of waste solvents (as much as 70 percent) and oils (about 10 percent) are currently recovered (see ch. 3). Several advanced thermal destruction techniques can recover or reutilize the chlorine content of chlorinated wastes. These technologies, however, have only been used on a small scale, primarily in Europe, and are not competitive with other sources of the recovered material. They have not been employed commercially in the United States and provide little or no capacity at the present time. Thus, **only modest increases in *recovery and recycling* of liquid organic hazardous wastes are expected in the near future.**

Much of the anticipated increase in recovery and recycling of hazardous wastes in the near future will involve wastestreams that have lit-

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[22] The two vessels are the *Vulcanus II* and the *Vesta*; the *Vulcanus I* is operational but not currently active.

[23] These issues are explored in ref. 14. Based on the definition used in that study, the term waste reduction is distinguished in this report from recycling and recovery; it generally refers only to those practices that reduce waste *at its source*. This definition excludes waste recycling, for example, unless it occurs as an integral part of an industrial process. Also see footnote 3.

tle or no potential for incineration, for example, metal-containing liquids and sludges. Development of ocean incineration and expansion of land-based incineration would not be expected to affect incentives for recycling or recovery of these nonincinerable categories of waste.

Estimating to what extent the implementation of waste *reduction* practices will affect the quantity of incinerable wastes generated is virtually impossible. In large part, this uncertainty is due to the lack of data and even appropriate means to measure waste reduction. The visibility and application of waste reduction measures are clearly increasing, and their potential to reduce the generation of hazardous waste is enormous. It is equally clear, however, that major institutional, economic, and attitudinal obstacles impede its widespread application in the near future (14).

Even the most optimistic observers of ocean incineration project a total industry of only several ships, which together would be capable of incinerating a small fraction of incinerable liquid waste, and an even smaller fraction of all hazardous waste. This probable market picture—together with limited or uncertain application of reduction, recovery, and recycling practices to incinerable wastes—argues that **the development of ocean incineration, as an interim option, would be expected to have a very limited effect on overall incentives for using these practices** (see chs. 2 and 3). There is no consensus, however, regarding this conclusion. Indeed, some critics strongly contend that ocean incineration will have a significant adverse effect on such incentives. OTA's policy options (discussed below) include provisions that could be used to ensure that the shift toward use of preferred practices is not impeded.

Recovery processes applied to liquid wastes generally produce residuals. Thus, increasing use of such processes is likely to increase the quantities of incinerable sludges and solids (which cannot be incinerated at sea) relative to the quantities of ocean-incinerable liquids. Many residuals from product purification as well as recovery processes, however, are in liquid form and are prime candidates for ocean incineration.

Thus, although significant long-term potential remains for further application of recovery and other emerging technologies, in the near-term they appear unlikely to substantially reduce the amount of incinerable waste (liquids as well as sludges and solids) requiring management through currently available means.

The Use of Ocean Incineration by Other Nations

Ocean incineration of hazardous wastes has been used routinely in Europe since 1969, and two incineration vessels are currently operating full-time in the North Sea. Opinions and positions regarding the future use of ocean incineration vary greatly among European and other developed nations. General agreement exists that incineration at sea should be viewed as an *interim* method for managing wastes, to be used only when preferable land-based alternatives are unavailable. No consensus currently exists, however, regarding when it will be possible to terminate its use.

In 1981, members of the Oslo Commission, which includes most Western European nations, adopted a rule stating that "the Commission will meet before the first of January 1990 to establish a final date for the termination of incineration at sea" in the Oslo Convention area (i.e., the North Sea). In 1985, a survey of Member States was undertaken to determine the feasibility of ending ocean incineration in the North Sea on or about that date. The survey documented the following trends:

- There is a potential shortfall in the capacity of land-based incinerators and other land-based treatment methods to dispose of the wastes currently being incinerated at sea. Spare capacity on land is considered far from sufficient, and very little increase in such capacity is expected in the near future.
- The major constraint blocking termination of ocean incineration is the lack of land-based capacity for chlorinated hydrocarbon wastes.
- It is expected that by 1990 wastes will remain for incineration at sea.

Certain nations, such as Denmark and Sweden, argue for termination as soon as possible; some nations, such as The Netherlands and the Federal Republic of Germany, regard ocean incineration as a necessary method for the foreseeable future because land-based incineration capacity is lacking;

and other nations, such as the United Kingdom, view ocean incineration of certain wastes to be the best practicable environmental option.[24]

Conclusion

The preceding discussions suggest the possibility that ocean incineration, carried out under a sufficiently rigorous and comprehensive regulatory framework (see discussion of policy options later in this chapter and ch. 2), could be one of several options to fill an interim need in hazardous waste management. Under such a scenario, ocean incinerators would focus on highly chlorinated liquid wastes (possibly including special wastes such as PCBs) that can be advantageously burned at sea because of the absence of a requirement for scrubbers. Land-based incinerators might concentrate on wastes that could not be burned elsewhere—organic sludges and solids with relatively high metal content and relatively low energy value. Liquids with high heat content but little or no chlorine might continue to be burned in industrial boilers and furnaces, though under stricter regulation where appropriate. Much of the expected application of waste recovery and recycling to incinerable wastes is expected to be applied to such liquids, and thus will produce organic sludges appropriate for land-based incineration. As capacity develops in better technologies, and as waste reduction practices are increasingly implemented, the use of ocean incineration should be concomitantly decreased.

DECIDING THE FATE OF OCEAN INCINERATION: MAJOR POLICY OPTIONS

Out of the controversy and polarization surrounding the development of ocean incineration, several disparate perspectives have emerged regarding whether and, if so, how to use this technology. The fundamental choice of *whether* to proceed cannot be resolved on a technical basis; it will require difficult political choices as well. Much of the debate has focused on the *whether* question in an all-or-none fashion. Certain intermediate alternatives, however, might be considered that would allow some use or further investigation, carried out in a manner that directly addresses the areas of disagreement.

Because ocean incineration has the potential to play an important but limited interim role in managing hazardous wastes, there is a need to consider a broad range of possible approaches to its use, including certain intermediate options. This intent is reflected in four distinct policy options OTA has identified:[25]

- *Option 1*: Halt the development of ocean incineration permanently and rely entirely on land-based options.
- *Option 2*: Halt commercial ocean incineration temporarily, until more research is completed. The research would probably require a few burns at sea to collect data needed to evaluate incinerator performance, to characterize emissions, and to assess environmental impacts.
- *Option 3*: Proceed with a commercial ocean incineration program under the regulatory framework being developed by the Environmental Protection Agency.[26]

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[24] There are further indications of the ambiguity with which Europeans view ocean incineration. For example, both The Netherlands and West Germany have reported that they anticipate significant decreases in their reliance on ocean incineration as a result of increases in land-based capacity. More recently, however, The Netherlands announced plans to conduct a trial burn of PCBs, in anticipation of the need for the ocean incineration option resulting from the loss of the country's land-based incineration capacity for PCBs (see ch. 12).

[25] This discussion is limited to consideration of policy options that affect the *fate* of ocean incineration. If a decision were reached to proceed with ocean incineration, numerous additional issues and options related to the *shaping* of an actual program would need to be addressed. Resolution of some of these issues may require regulatory action on the part of EPA or oversight on the part of Congress; others may necessitate additional legislative action. Detailed discussion of these issues is presented in ch. 2.

[26] In this report, EPA's developing regulatory framework is represented, for the most part, by EPA's proposed Ocean Incineration Regulation (50 FR 8222, Feb. 28, 1985). Several substantial changes are expected during finalization of this regulation, some of which may directly bear on issues discussed under option 4.

- *Option 4*: Proceed with a *modified* ocean incineration program that would accomplish one or more of the following:
  - A. include provisions that impart an *interim* status to the program;
  - B. strengthen regulatory requirements where necessary to address areas of deficiency or continuing public concern; and/or
  - C. provide for greater direct involvement by the government in the actual operation of ocean incineration.

For options 3 and 4, numerous factors would determine the scale of the program. These include influences from market factors, government intervention, public opposition, and modification of the regulatory program in response to new information. Many of the factors could be subject to direction through regulatory or economic measures, but others would be more difficult to predict or control.

Policy Options and Their Implications

Each of these policy options has certain implications when viewed in the context of overall management of hazardous wastes. Moreover, each choice necessarily engenders additional decisions that must be made. Some of the possible implications of each option are presented below.

Option 1:
Halt the development of ocean incineration permanently and rely entirely on land-based options.

Implications

1. Land-based incineration capacity for incinerable wastes would lag even further behind demand. If three of the existing incineration vessels[27] were used, the *commercial* incineration capacity for liquid wastes would roughly double. In their absence, efforts to expand the capacity of land-based incineration or other alternative technologies would need to increase.

2. The increased shortfall between incineration capacity and demand might cause some limited increase in incentives for waste reduction, recycling, and innovative treatment of incinerable liquids. The need for currently available waste treatment options would clearly continue into the foreseeable future, however, because of the sheer quantities of wastes, the time required to implement waste reduction measures and to develop sufficient recycling capacity, and the fact that not all wastes will lend themselves to such techniques.

3. The incentive for waste generators to manage their incinerable liquid wastes onsite would be expected to increase somewhat, which might mean an increase in noncommercial incineration or other treatment capacity. Reliable estimates of the extent of this increase do not exist.

4. If sufficient alternative capacity were not developed, wastes would continue to be disposed of on land, often using practices that pose demonstrated risks to the environment and human health. Under the Hazardous and Solid Waste Amendments of 1984, wastes to be banned from land disposal could be granted variances or extensions if sufficient alternative treatment, recovery, or disposal capacity were not available.[28]

5. More incineration would take place in land-based facilities closer to human populations, thereby increasing direct human exposure to incinerator emissions. At the same time, the risk of a spill or other adverse impact on the marine environment would not be increased.

6. Prices charged to generators to dispose of at least some incinerable hazardous wastes (e.g., PCBs) would probably rise, because of increased demand on available capacity. This same factor might also increase existing pressures to dispose of hazardous waste illegally.

Option 2:
Halt commercial ocean incineration temporarily, until more research is completed. The research would probably require a few burns at sea to collect data needed to evaluate incinerator perform-

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[27] It is assumed that three incineration vessels would operate primarily in the United States: the *Apollos I* and *II* and the *Vulcanus II*. The remaining vessels are assumed to continue operating in Europe.

[28] Sec. 201(h) of the amendments specifies that such variances or extensions may be granted for a maximum of 2 years. The course of action that would ensue after 2 years if alternative capacity were still unavailable is not clear.

ance, to characterize emissions, and to assess environmental impacts.

Implications (in addition to those for Option 1)

1. A climate of extended regulatory uncertainty probably would significantly impede or halt new investment in the ocean incineration industry. The recent bankruptcy of the builder of the *Apollo* incineration vessels and their owner's subsequent loan default are widely attributed to their inability to obtain an operating permit. Some companies currently awaiting program development might decide to abandon plans to enter the market.

2. Research would probably answer some questions and narrow the overall window of uncertainty. It should be relatively easy, for example, to improve our understanding of the composition of incinerator emissions and at least their initial environmental behavior. Nevertheless, numerous questions, especially those involving the risk of spills or cumulative adverse environmental impacts, would probably only be resolved through experience on a larger scale.

3. If a decision were ultimately made to proceed with ocean incineration, the ensuing program would probably benefit from information gleaned through research. Incorporating such information into a regulatory program during its development would probably be easier than modifying an ongoing program.

4. The question of when *enough* research had been done would have to be faced. Comparable attention to information gaps in other alternatives would be necessary, including land-based incineration, to provide a valid comparative risk assessment. After any amount of research, some level of uncertainty would always remain, and decisions would have to be made in the face of incomplete information.

5. Criteria for determining the type and number of ocean research burns to conduct would need to be developed and evaluated. For example, EPA's Ocean Incineration Research Strategy (16) calls for using PCB waste because both the toxicity characteristics and the detection methods for PCBs have been well studied. Because typical ocean incineration wastestreams would probably be composed of complex mixtures of many different chemicals, however, the applicability of results from this test burn to real situations would be limited.

6. The question of *who* should do the research would also need to be faced. Widespread public mistrust currently exists as to whether EPA or industry could objectively carry out the research. Addressing this credibility gap or identifying alternative ways to perform the studies or to assure credible results would not be an easy task.

Option 3:
Proceed with a commercial ocean incineration program under the regulatory framework being developed by the Environmental Protection Agency.

Option 4:
Proceed with a *modified* ocean incineration program that would accomplish one or more of the following:

A. include provisions that impart an *interim* status to the program;
B. strengthen regulatory requirements where necessary to address areas of deficiency or continuing public concern; and/or
C. provide for greater direct involvement by the government in the actual operation of ocean incineration.

In contrast to the first two options, options 3 and 4 both involve a choice to employ ocean incineration on a routine basis.[29] Options 3 and 4 differ from each other primarily in how much they would dictate or influence the scale of the ocean incineration program. The discussion of these options, therefore, begins below by examining factors that might influence the extent to which ocean incineration would be used. The discussion also explores some of the implications of proceeding with ocean incineration on various scales.

Option 4 goes beyond the status quo approach of option 3, by suggesting several approaches to addressing certain of the key deficiencies or potential uses of ocean incineration that OTA has identified. The discussion considers several possible departures from EPA's proposed program, both to address specific shortcomings and to illustrate the potential for modifying the current approach to using ocean incineration. Most importantly, the discussion suggests certain mechanisms that might help to ensure that any ocean incineration program that developed would be instituted in an *interim* manner, allowing the reliance on ocean incineration to decrease as capacity in better alternatives develops.

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[29] The actual *shaping* of an ocean incineration program would involve numerous additional technical and policy factors that are discussed in ch. 2.

Determining the Scale of an Ocean Incineration Program

Influences

Although innumerable factors would influence the scale of an ocean incineration program, many could be directly controlled through regulatory or economic measures. Depending on how much control the government exerted, the scope of the program could be tentative or experimental in nature, could evolve in an essentially free market setting, or could entail active government promotion or involvement.

Regardless of the intent and extent of the controls, however, predicting the actual scale of ocean incineration would be difficult. This source of uncertainty would complicate the task of estimating resource allocation and regulatory needs, and of predicting how ocean incineration would affect hazardous waste management in general. Sufficient resources must be available for regulatory and monitoring activities to ensure safe operation and to allow the collection of reliable data on which to base future decisions. Moreover, the question of who should pay for these activities must be addressed. The availability of resources, particularly in a time of fiscal restraint, must be seriously considered in developing and designing a regulatory program.

Four categories of "scaling" factors are discussed below:

1. *Market Factors*: These are factors that directly influence the costs of doing business either for those who generate wastes or for those who own and operate incineration facilities. These costs would, of course, be strongly influenced by regulations or other government actions (see below). Market factors would include how much waste generators would have to pay for ocean incineration services compared to how much other alternatives cost; the availability and regional distribution of ocean incineration sites and of port facilities for storage and transfer of wastes; and how much new capital investment would be required to develop such facilities.

   The current economic status of incinerable liquids with high fuel value (i.e., energy content) exemplifies the influence of market factors. Such wastes currently represent a very competitive market, comprised of industrial boilers and furnaces, recovery and recycling operations, and land-based incinerators. The predictable result is that wastes move in the direction of lowest costs to generators (within regulated bounds). The entry of ocean incineration into such a market would result in adjustments based largely on how competitively priced the new services were.
2. *Government Intervention*: Ocean incineration, if developed, would obviously be subject to tremendous governmental attention, which could take both regulatory and nonregulatory forms. Regulatory requirements could, for example, influence the market for ocean incineration by affecting the quantities and types of waste available for ocean incineration (e.g., limitations on waste composition; requirements to demonstrate a need to incinerate at sea) or the costs of doing business (e.g., requirements for liability and financial responsibility; fees for monitoring and permitting). Nonregulatory influences might include economic incentives or disincentives or direct government support measures (e.g., loan guarantees; taxes assessed on the quantity of waste generated or disposed; government ownership or operation of incineration vessels).

   Broader government regulatory actions influencing hazardous waste management in general could exert significant indirect influence over the use of ocean incineration. Examples of such factors include the extent and schedule of implementation of the 1984 RCRA restrictions on land disposal and the development of siting criteria for disposal facilities.

3. *Public Opposition*: EPA's attempt to develop a regulatory program for ocean incineration has encountered growing public opposition to all phases of operation: locating port facilities for storing and transferring wastes; transporting wastes over land to port sites; designating sites for ocean incineration; setting requirements for permits and liability; and regulating the incineration process itself. The public has also been critical of the adequacy of mechanisms for ensuring meaningful public education and participation.

   Perhaps most important, the public has questioned whether EPA can objectively develop and administer a regulatory program for ocean incineration. Indeed, legitimate public concern exists over the potential for significant conflict of interest between EPA's promotional and regulatory roles. Clearly, additional means of addressing public concerns must be developed as part of any future program.

4. *"Feedback"*: Another factor that would influence the scale of an ocean incineration program would be any response taken to account for new information obtained through experience or monitoring. As operations proceeded on any scale, data would need to be gathered and analyzed to answer unresolved questions and to evaluate the adequacy of the regulatory program. Such data might relate to accident rates, the relative safety of different technologies, the effectiveness of particular regulatory measures, the results of environmental monitoring, or the program's influence on progress toward implementing measures to reduce waste or developing preferable treatment alternatives.

   The regulatory program's ability to respond to the new information would depend on numerous factors, such as the effectiveness of the data-collection efforts, the ability of the regulatory and political processes to accommodate needed changes in a timely manner, and the nature of the gathered information itself. Mechanisms would have to be developed for modifying the scale of the program if the data indicated that adjustments were warranted.

Two examples illustrate the potential need for adjustments:

1. Further controls or incentives might be required if the market outlook for ocean incineration conflicted with waste management policy. For example, as capacity in preferable alternatives such as recycling and recovery developed, economic or regulatory measures might be needed to redirect wastes from ocean incineration to these options. Such measures could be particularly important to ensure the *interim* status of the ocean incineration program.
2. New scientific information or regulatory requirements might arise. For example, the cumulative effects of large-scale incineration at a single site could become significant and require attention.

Specific Approaches

The proposed regulatory framework for ocean incineration contains few provisions that would directly limit the scale of the program. As currently formulated, it could be expected to result in a relatively open-ended (although highly regulated) system, whose size would largely depend on private initiative and investment and on the operation of the market. This approach would be consistent with the current regulatory approach to land-based incineration and certain other hazardous waste technologies.

Recent statutory and regulatory attempts to shift hazardous waste management away from some traditional land-based disposal options and toward better treatment technologies provide examples of the government's intervention into the market for the purpose of achieving a desired waste management goal. Congress and EPA might wish to consider analogous measures for controlling the use of ocean incineration, particularly if interim status were the desired goal. OTA has identified several possible approaches.

Permit Ocean Incineration Only for Wastes for Which a Need To Incinerate At Sea Can Be Demonstrated.—Whether there is a need for ocean incineration is the subject of both public and legal concern. The issue of need is closely related to the question of how ocean incineration would affect the use of better waste management or waste reduction alternatives. (See ch. 2 for a fuller discussion of both of these issues.) OTA expects that developing ocean incineration would probably not significantly impede the development and implementation of preferable alternatives. Certain regulatory measures could be applied to users of ocean incineration, however, to ensure that the best available options are used to manage or reduce the generation of incinerable wastes.

Such measures, which could be implemented through the permitting process, might require a waste generator to demonstrate that ocean incineration would be better than (or at least not inferior to) the other available options. Alternatively, the measures could require the waste generator to demonstrate that no feasible land-based alternatives were available for a particular waste. A third approach would be to use the permitting process to link use of ocean incineration to compliance with a schedule for achieving particular levels of waste reduction, recovery, or recycling.

For these sorts of measures to succeed, several implementation problems would have to be resolved (see ch. 2). Nonetheless, mechanisms of this sort could provide concrete means to ensure that ocean incineration was indeed employed in an *interim* manner.

Direct Certain Wastes Toward or Away From Ocean Incineration.—OTA's finding that **highly chlorinated wastes** might be more beneficially incinerated at sea than on land suggests the possibility of encouraging or even requiring the use of ocean incineration for such wastes (assuming they meet other applicable criteria).

EPA has proposed limiting the **metal content** of wastes to be incinerated at sea. The adequacy of the proposed limits, however, is at issue (see ch. 2), and will likely require further scrutiny and possible revision of the proposal. If the final regulation maintains the lack of a requirement for scrubbers on incineration vessels, adequate control over metals will be an essential regulatory element. Limiting the metals would, in turn, affect the types of incinerable wastes that could qualify as candidates for ocean incineration.

The **energy content** of wastes might also be a factor in determining which wastes would be incinerated at sea. High-energy wastes are currently managed using several different technologies or practices, as described previously. Land-based incineration companies compete for such wastes to use as fuel in order to reduce the need for supplementary raw fuel to burn low-energy wastes (e.g., various organic solids and sludges; see ch. 2). Industrial boilers and furnaces can also burn high-energy wastes in order to recover their energy content, again as an alternative to burning raw fuel. If the government were to decide that *public* benefit (as opposed to private economic benefit[30]) was sufficient to justify such uses, then a restriction might be placed on the burning of high-energy wastes at sea.

Finally, considerable attention has focused on using ocean incineration to burn **special wastes**, such as PCBs and DDT. Proponents of ocean incineration cite the properties that render such chemicals so troublesome (environmental persistence, toxicity, ability to bioaccumulate, and resistance to burning) as reasons why these special wastes *should* be burned at sea, whereas opponents of ocean incineration cite the same properties as reasons why such wastes *should not* be burned at sea. The dichotomy in this debate reflects whether one's main concern is with direct exposure and impact to humans *or* the marine environment. The potential use of ocean incineration for such wastes would need further evaluation. Such an evaluation would be particularly important in light of current regulations requiring incineration of PCBs (see box B in ch. 3).

Both regulatory and economic approaches to directing particular wastes toward or away from ocean incineration might be warranted if Congress or EPA decided to encourage or restrict the use of ocean incineration for any of the wastes described above. Obviously, because they could significantly affect the overall market for either included or excluded wastes, such measures would therefore need to be assessed from a broad perspective.

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[30] Obviously, the private firms involved would experience a savings in fuel costs. This argument has been used by land-based incineration companies in their opposition to ocean incineration (see ref. 9, for example). Proponents of ocean incineration claim that the land-based companies are simply wary of more competition, and that the market should decide where such wastes go (see ch. 2).

Geographically Restrict the Transportation of Wastes To Be Incinerated At Sea.—Transporting and importing wastes generated in one area to another area for storage and loading onto an incineration vessel has engendered a significant amount of public concern. These issues have raised questions of *equity* with respect to who should bear the risks and enjoy the benefits of using ocean incineration. Such questions are by no means unique to the issue of ocean incineration.

Implementation of geographic limitations on the transportation of wastes for the purpose of incineration at sea might help to address some of the public concern. These limitations might take any of several forms, including specifying a maximum distance for land transport, directing wastes to ports most suitable for handling them, or requiring the use of particular burn sites for particular wastes. In conjunction with designating multiple sites for ocean incineration and with developing port selection criteria (see ch. 2), geographic limitations could help to address the equity issue by requiring wastes to be managed near their points of origin.

Because most incinerable wastes are generated in coastal States (see ch. 3), geographic restrictions probably would not significantly reduce the potential market for ocean incineration. The restrictions could pose difficulties, however, if several companies wished to operate out of the same port. It could also place unprecedented restrictions on one set of commercial activities—ocean incineration—without affecting comparable activities such as land-based incineration[31] or marine commerce in hazardous materials.

Restrict the Number of Operating Permits.—If the Nation were to proceed with a provisional or experimental program of ocean incineration, Congress or EPA might want to specifically limit the size of the fleet or the number of vessels in operation at any given time. This could be accomplished by granting permits only to existing vessels or to some predetermined number of vessels, based on particular criteria such as the expected market size, the desired frequency of operation of incineration vessels at existing sites, or the level at which monitoring could be feasibly performed.

The public has repeatedly raised the question of the credibility of private companies and their ability to comply with all regulatory requirements. Some observers have called for the development of criteria to allow consideration of a company's compliance record as an integral part of the permitting process. In addition, demonstrating financial responsibility would be a minimum requirement for receiving a permit, although the level and the nature of liability to be required for ocean incineration have yet to be determined (see ch. 2).

Using criteria such as these to restrict the number of permits granted would limit the scale of the program and would specifically address key public concerns. However, this approach might severely curtail new investment into ocean incineration and, therefore, could limit expansion of the fleet that might be desired at a later date or hamper research and development aimed at improving existing ocean incineration technology.

Restrict the Period for Which Permits Are Granted.—EPA's proposed Ocean Incineration Regulation would grant individual ocean incineration operating permits for 10 years, subject to renewal after 5 years (or more frequently at the request of the Assistant Adminstrator). Critics have raised legitimate questions over whether a 10-year permit length would be appropriate in a new program. To attract private investment, of course, some degree of business certainty and sufficient opportunity for making profits would be necessary.

In any event, determining the appropriate length of permits provides an additional opportunity for controlling the scale of an ocean incineration program, and should be a consideration in resolving the ongoing debate on this issue. See chapter 2 for further discussion of this issue.

Implement One or More of the Above Conditions During a "Trial Period."—Regardless of the nature and number of research burns undertaken, numerous questions will remain unanswered until an actual ocean incineration program is operating. Even if an open-ended program were the eventual goal, however, gaining some operational experience on a limited scale in the beginning would be useful, if not essential. Thus, even if the approaches discussed above were deemed too restrictive or unworkable in the long run, invoking them at the start of the program might still be warranted.

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[31] The scarcity of commercial land-based incinerators in some regions of the country commonly results in wastes being transported considerable distances to reach existing facilities—in some cases, further than would be required to reach port facilities.

The appropriate length for such a trial period would be difficult to determine in advance. Predicting when enough experience has been gained to make a final decision—to proceed with a larger program, to maintain a limited program, or to terminate the activity entirely—would be difficult because some uncertainties and risks would remain after any period.

Provide for the Government To Own or Operate Incineration Vessels.—This option is arguably the most extreme of those considered, because of its radical departure from the traditional and widespread private approach to hazardous waste management in this country, and the potential conflicts of interest associated with direct entry of the government into such a controversial enterprise.

This approach, however, would provide a very direct mechanism for controlling the scale of an ocean incineration program, in that the government could determine the quantities and types of wastes it would burn in its own ships.[32] Moreover, because government-sponsored ocean incineration could potentially occur in a nonprofit-driven setting, the government could more easily reduce or terminate the program, if and when that were deemed desirable. This approach could very directly and relatively easily ensure that ocean incineration would be viewed and conducted as an *interim* program.

Serious obstacles to government ownership, however, are equally apparent. Perhaps the most troublesome is that it would juxtapose regulatory and promotional roles that many members of the public regard as too close already. Indeed, the potential for significant conflict of interest would greatly increase and would need to be specifically addressed. Given the already low degree of public confidence that EPA could objectively develop and administer a regulatory program for private ocean incineration, the concept of public ownership may simply be too precarious to be seriously entertained.

SHAPING AN OCEAN INCINERATION PROGRAM

The fundamental policy issue concerning ocean incineration is whether to proceed with development of a regulatory program. Although this decision will require difficult political judgments, analyzing particular issues from a technical perspective can help clarify the implications of various alternatives and help design ensuing programs if ocean incineration is allowed. To this end, OTA has identified and analyzed a large number of technical factors that bear directly on such a decision. Several key policy issues have emerged from this analysis, and are briefly introduced below. Chapter 2 discusses each of these issues in greater depth, and analyzes various regulatory and policy options that might be implemented to resolve these issues.

Regulation of Incinerator Emissions

One important policy issue is whether proposed regulations governing incinerator emissions are adequate. In regulating emissions from ocean incineration, EPA has proposed to extend the approach it originally developed for regulating land-based incineration, which is based primarily on measures of *incinerator* performance.[33] This approach emphasizes the attainment of a particular level of destruction of wastes, as opposed to establishing numeric limitations on each of the many components of the emissions. The basis for this approach lies in the extreme complexity both of the wastes and of the emissions that are generated when hazardous wastes are incinerated. This complexity precludes routine measurement of all components.

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[32] This option is not entirely academic: the government may, in fact, now own two incineration vessels, because of the recent bankruptcy of Tacoma Boatbuilding, Inc., and the subsequent loan default of its subsidiary, At-Sea Incineration, Inc.

[33] EPA has also proposed certain *environmental* performance standards that would indirectly apply to emissions.

To make the tasks of monitoring and regulating incineration manageable, EPA limits the number of compounds to be analyzed to a small set of compounds that is chosen to be as representative of the entire waste as possible. Incinerator performance is then gauged by measuring the destruction efficiency (DE) for these preselected compounds.[34] EPA's proposed reliance on the DE performance standard has been criticized on several bases.

- EPA's definition of DE does not provide an adequate measure of destruction for all components of the waste or for all possible sets of operating conditions.
- Methodologies for sampling emissions and monitoring incinerator performance are not well developed or have not been verified through actual experience.
- Incinerator emissions have been insufficiently characterized and quantified to permit a valid evaluation of the need for specific emission standards, particularly for metals.
- The toxicity of incinerator emissions, particularly with respect to possible long-term impacts, has not been sufficiently examined.
- The identity, origin, and toxicity of products of incomplete combustion (PICs) have been insufficiently studied, precluding an assessment of their significance and of the possible need for regulation.

Transportation Risks

A second key policy issue concerns the extent and nature of land and marine transportation risks associated with ocean incineration. The transportation of hazardous waste is regulated under many authorities at the Federal, State, and local levels. For the purpose of regulating ocean incineration, EPA is proposing few specific controls beyond those already generally applicable to incineration vessels and associated waste transportation and transfer activities. The adequacy of such an approach has been questioned and several areas needing additional attention have been identified:

- Applicable regulations under other agencies need to be referenced and applied specifically to ocean incineration.
- Explicit mechanisms are needed to ensure adequate interagency coordination and delegation of authority for enforcement and monitoring.
- Criteria are needed for selecting and designing ports to be used for ocean incineration.
- Contingency plans and emergency response capabilities need to be developed and coordinated.

Comparison of Different Ocean Incineration Technologies

A third key policy issue concerns the need for a comparative evaluation of different technologies for ocean incineration. Several different designs exist or have been proposed for incinerator vessels and associated facilities. These designs could differ significantly with respect to safety and performance. A thorough comparative assessment of different designs may be necessary to ensure the use of the best available technology for ocean incineration. In addition, mechanisms for incorporating newly developed alternative or superior design features into the regulatory program must be developed.

Equitable Regulation

A fourth key policy issue involves equity in the regulation of land-based and ocean incineration. Because land-based and ocean incineration are regulated under different statutes, numerous differences exist in regulatory requirements and expectations. Many provisions that apply only to one of the technologies, or are more stringent for one or the other, have stirred considerable debate. Often, such provisions are necessary or desirable to account for differences between the technologies in, for example, the kinds of risks they pose or where they are used.

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[34] For land-based incinerators equipped with air pollution control devices (i.e., scrubbers), the destruction performance standard is actually a destruction *and removal* efficiency (DRE). DRE is measured *after* the operation of scrubbers. In practice, however, EPA has found that DE and DRE are functionally equivalent, because scrubbers are very inefficient at removing the organic substances that are measured in calculating DE or DRE.

Given such differences, simply adopting identical sets of regulatory requirements is not likely to accomplish equitable regulation of land-based and ocean incineration. The technical and nontechnical bases for any differential regulations, however, should be subjected to thorough scrutiny and made as explicit and open to review as possible.

Public Involvement

A fifth key policy issue is whether public involvement in decisions regarding ocean incineration is adequate. Public opposition to ocean incineration has arguably been the major impediment to development of a regulatory program. At the same time, public involvement has played a substantial role in broadening the scope of the debate over ocean incineration to include consideration of the need to develop a national strategy for managing hazardous wastes.

The nature and extent of public opposition to ocean incineration suggests that available mechanisms for involving the public in the decisionmaking process are woefully inadequate. Although this problem is by no means confined to the subject of ocean incineration, additional mechanisms aimed at ensuring and encouraging meaningful public participation and education are essential to any future regulatory program for ocean incineration. In addition, if any ocean incineration program is to go forward, specific steps must be taken to address and resolve outstanding public concerns surrounding ocean incineration.

The Effect of Ocean Incineration on the Development of Better Alternatives

A sixth key policy issue is how an ocean incineration program would affect the development and implementation of environmentally preferable waste treatment, recovery, and reduction practices. A major point of contention has been whether ocean incineration would undermine existing incentives for using and developing better practices and technologies for hazardous waste management. Although OTA's analysis suggests that such an effect is likely to be limited, prudence may dictate taking steps to ensure that waste reduction is implemented wherever possible and that the remaining incinerable wastes are, in fact, directed toward the best available management practices. To this end, certain policy directives or regulatory requirements, specifically applying to users of ocean incineration, might be desirable. Particularly deserving of serious attention are measures that would ensure and increase the *accountability* of waste generators that choose to utilize ocean incineration. Other regulatory and economic means of affecting the role that ocean incineration plays in hazardous waste management may warrant congressional action.

Unresolved Questions

A seventh key policy issue concerns the seriousness of unresolved questions about the operation and impacts of ocean incineration. Significant debate centers on whether enough information is currently available to allow an informed decision on whether and, if so, how to proceed with a program for ocean incineration. Although most observers acknowledge that many unresolved questions remain, consensus is lacking on which questions, if any, need to be answered before ocean incineration can be permitted and on what means should be used to answer such questions.

Many of the unresolved questions about ocean incineration apply equally to already permitted activities, such as land-based incineration. Consequently, questions arise regarding whether, how much, and when research should be done on these alternatives, and how such research should relate to that required for ocean incineration.

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Chapter 2

Shaping an Ocean Incineration Program: Key Policy Issues

If Congress decides to allow the development of an ocean incineration program, several key regulatory and policy issues will need to be resolved to provide an equitable, efficient, and environmentally sound approach to managing the activity. Despite debate over the significance or means of resolving the outstanding issues, general agreement exists as to what the issues are. This chapter examines some of the issues that are key to the design of an ocean incineration program. The discussion provides a range of policy or regulatory options that might be used to resolve these issues.

For each issue, the discussion describes current controls or approaches,[1] followed by a range of additional or more extensive controls and approaches that are oriented toward the same general end.

The chapter discusses technical issues, which primarily concern the incineration technology; nontechnical issues, which concern institutional or social structures that affect regulation of ocean incineration; and issues, both technical and nontechnical, that influence how ocean incineration fits into an overall waste management strategy. The chapter also discusses several additional issues that have generated significant public concern.

TECHNICAL ISSUES AND OPTIONS

Controlling Stack Emissions From Incinerator Ships

Current Controls

EPA's proposed regulation would approach this issue indirectly, controlling waste composition and incinerator performance, rather than limiting the emissions themselves. The regulation would limit the quantities of metals allowed in wastes to be incinerated, as a means of controlling particulate and metal emissions. Two methods of monitoring incinerator performance would be used to control emissions of unburned or partially burned waste. First, trial burns would determine operating conditions that would achieve the required destruction efficiency (DE) (see ch. 7), and all subsequent burns would have to utilize these conditions. Second, incinerator operators would be required to monitor combustion efficiency (CE) continuously and maintain a minimum level, which would serve as a partial surrogate for the DE requirement.

Under the proposed regulation, no limitations or standards would be specified for particular components of the emissions themselves. Instead, the regulations would require compliance with two environmental performance standards. First, acid-forming emissions (primarily hydrogen chloride gas) would be limited to amounts that would not change the alkalinity of the water by more than 10 percent. Second, emissions would be limited to amounts that would not "unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems or economic potentialities or recreational or commercial shipping or boating or recreational use of beaches or shorelines." Such amounts would generally be determined by referring to appropriate marine water quality criteria, where they exist.

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[1] Discussions of EPA's approach generally refer to the approach set out in EPA's proposed Ocean Incineration Regulation (50 FR 8222, Feb. 28, 1985). Many of the provisions discussed in this report are expected to change in the process of finalizing the regulation, but the changes cannot yet be identified and, therefore, cannot serve as a basis for discussion.

Additional Controls

Numerous more stringent controls on ocean incinerator emissions have been proposed. The following discussion focuses on two types of additional controls: those that are not currently imposed on either land-based or ocean incinerators but that are relevant to both; and those that are currently imposed on land-based incinerators but would not be imposed on ocean incinerators under EPA's proposed regulation.

Proposals Applicable to Incineration Both on Land and At Sea.—Five proposals for additional controls would be relevant to both land-based and ocean incineration.

1) *Redefine Destruction Efficiency To Provide a Measure of Complete Destruction of All the Waste Constituents That Are Present.*—EPA would require demonstration of the ability to attain a minimum destruction efficiency for a preselected set of parent compounds known as Principal Organic Hazardous Constituents (POHCs). The compounds chosen as POHCs would be present in high concentrations in the waste and/or difficult to destroy completely by burning. The definition of DE would be based on two major assumptions: 1) that if a compound disappeared, it must have been completely destroyed; and 2) that if the preselected compounds were abundant and were more difficult to destroy than were all other components, the rest of the waste would be destroyed with equal or greater efficiency. The validity of both assumptions, however, has been questioned by several observers, including EPA's Science Advisory Board:

> As long as the definition of DE addresses only the disappearance of the parent POHC and does not take into account products of partial decomposition or products newly synthesized in the incineration process, the definition is limited in its ability to aid in the assessment of total emissions and subsequent assessments of environmental exposures (12).

Several alternative approaches to determining DE have been proposed (12,15). Some have been used in actual testing of incinerator vessels, and EPA is currently conducting research to evaluate their validity and potential use (5). The alternative definitions are based on a total destruction efficiency, or TDE, derived by measuring the total quantity of organic material released in emissions. Several variants of this approach have been used, including measuring emissions of organically bound chlorine or of difficult-to-incinerate tracer compounds added to the waste prior to incineration.

The DE standard measures performance by focusing on what incineration destroys and removes from wastes. The standard does not regulate what actually comes out of the incinerator. It provides no measure of the absolute *quantity* of organic material released into the environment. EPA has considered adopting two other standards that would measure actual emissions (14). One is a mass emission *rate* standard, which would regulate the quantity of organic emissions released per unit of time; the other is a mass emission *concentration* standard, which would limit the quantity of emissions per unit of volume. Although these standards provide measures that could be used directly to assess exposure and risk, the only bases for setting the standards would be technology or risk. Technology is already used as a basis for the DE standard; risk would have to be derived on a facility-by-facility basis, which would impose tremendous data, monitoring, and administrative burdens.

For these reasons, EPA opted for the uniform performance-based DE standard. Particularly harmful constituents, however, might warrant action to regulate emissions further by limiting the rate at which wastes can be burned or by requiring a higher DE. Permits for incineration of wastes containing polychlorinated biphenyls (PCBs), in fact, have limits on PCB content or the rate at which the wastes can be fed into the incinerator (48 FR 48986, Oct. 21, 1983).

2) *Require Complete Analysis of the Chemical Characteristics of the Emissions That Would Arise Under a Variety of Operating Conditions. Based on Such a Characterization, Emissions Standards for Particular Components May Be Needed.*—The Science Advisory Board (SAB) found that "incinerators can be built and run under a set of optimal conditions so that the DE for the selected POHCs can meet specified criteria of 99.99 percent (for most wastes) to 99.9999 percent (for PCBs)." Because

DE would not be measured on a continuous or even periodic basis, however, the SAB found that it would not adequately account for variability in incinerator performance, particularly for incinerator upsets, which might be brief but could significantly reduce the time-averaged DE.

Calculating DE during deliberately created upset conditions or monitoring DE continuously during operational burns, as well as trial burns, has been proposed. Unfortunately, current analytical methodologies are not rapid enough for DE to serve as a means of monitoring incinerator performance. EPA proposed relying on combustion efficiency as the best available substitute for DE, although a strong correlation between CE and DE has not been established. The SAB called on EPA to develop a revised DE that adequately accounts for the well established variability in how incinerators perform.

The SAB also recommended that a complete characterization of incinerator emissions be performed, analyzing the chemical composition of the emissions produced under a variety of operating conditions. Many observers have called for the characterization and regulation of *metal emissions*, based on anticipated environmental effects. This proposal may be particularly important because, under EPA's proposed regulation, waste limitations would control the amount of individual metals allowed in the waste, but would not control the waste's *aggregate* metal concentration (see proposal 5 below).

Both land-based and ocean incinerators could be significant sources of nitrogen and sulfur oxides and of other hazardous air pollutants. The EPA regulation, however, would not require control over or even consistent monitoring for such components in stack emissions. Both the Resource Conservation and Recovery Act (RCRA) and the Clean Air Act regulate land-based incinerators, but emissions standards apply only to total particulates and acid gases. For ocean incineration, acid-forming emissions are regulated through an environmental performance standard for *seawater*, but this standard does not regulate any substances as hazardous *air* pollutants.

3) *Require Tests of the Short-Term and Long-Term Toxicity of Emissions.*—The SAB called on EPA to determine the toxicity of representative incinerator emissions in a manner that would address both short- and long-term effects. The tests should be performed on a representative number and range of species and life stages. The tests should also account for environmental mechanisms that are capable of concentrating emission products (e.g., by trapping organic constituents in the ocean surface microlayer; see ch. 9).

4) *Limit Emissions of Products of Incomplete Combustion (PICs).*—Data on the generation and toxicity of PICs are scarce, although such highly toxic compounds as dioxins and dibenzofurans have been identified among the PICs created in hazardous waste incinerators. EPA's proposed regulation would not regulate PICs, partly because of the lack of data on how operating conditions are correlated with the formation of PICs. EPA has, however, offered two possible approaches to controlling PICs under future regulations (50 FR 8247, Feb. 28, 1985).

First, emissions limits could be established on a PIC-by-PIC basis, reflecting the applicable water quality criteria or marine aquatic life no-effect levels. Water quality criteria, however, currently do not exist for most PICs and would have to be developed. Moreover, monitoring for PICs could not be carried out during routine operations because of the complexity of analysis required.

A second approach would be to limit the total quantity of unburned hydrocarbons allowed in emissions. In effect, this approach would set an upper limit on PIC emissions, but individual PICs would not be identified or limited.

5) *Limit Metal Emissions.*—The proposed Ocean Incineration Regulation would specifically limit the amount of each of 14 metals that could be present in waste to be incinerated at sea (50 FR 8244, Feb. 28, 1985). Two types of limitations were proposed, one on the wastes that are initially accepted for incineration and one on the final blended waste fed to the incinerator.

Concentrations of each of the metals in *wastes accepted for incineration* at sea would be limited to 500 parts per million (ppm) per metal. The *aggregate* concentration of all metals in the waste, however, would not be limited. Thus, a waste containing metals far exceeding 500 ppm could be legally accepted for incineration. Critics also point out that no scientific basis exists for setting the metal limitations at 500 ppm, and that the limitations should be metal-specific and risk-based. In practice, the actual concentrations of metals in wastes that have been incinerated at sea have generally been far below the 500 ppm level (see ch. 8), so lowering this standard—at least for the more toxic metals—might not significantly affect the range of wastes that could be accepted for ocean incineration.

Because incinerator ships do not have scrubbers, all metals in the waste are presumed to exit through the stack directly into the environment. In light of this, EPA proposed a second limitation, in this case on the concentrations of metals in the *final blended waste that is fed to the incinerator*. These concentrations would be limited to amounts such that the resulting *emissions* would not exceed marine water quality criteria, after accounting for initial atmospheric and oceanic dispersion.[2] This limitation is scientifically based, since marine water quality criteria are developed on the basis of metal-specific toxicity data. Of the metals listed above, EPA has determined that mercury, silver, and copper must be limited below the 500 ppm level to meet marine water quality criteria (50 FR 51362, Dec. 16, 1985).

The proposed regulation would appear to provide special treatment for mercury and cadmium because of their special treatment in international (London Dumping Convention, or LDC) and domestic ocean dumping regulations. Emissions of these two metals, however, actually would be subject to the same standards as would other metals; that is, they would be limited "to that amount which if directly dumped would not exceed *their applicable water quality criteria*" (emphasis added). Thus, despite language apparently singling out these two metals, the proposed regulation would limit all 14 metals in the same manner.

Finally, in addition to the absolute amount, the *chemical form* of a metal plays an important role in determining the metal's environmental fate and effects (see ch. 7). The chemical forms, as well as quantities, of particular metals in incinerator emissions have not been fully determined. **Undertaking such a characterization of the emissions would be essential for justifying the lack of a requirement for scrubbers on incineration vessels.** Further regulation of metal emissions might well be warranted, given EPA's finding that most of the human health risks associated with ocean incineration would be derived from metal emissions (11).

The potential need for stricter regulation of metal emissions also applies to land-based incinerators, where total particulates are regulated, but no monitoring or regulation of individual metals is required.

Proposals Extending Current Land-Based Incineration Requirements to Ocean Incineration.—Two proposals would extend to ocean incineration some requirements that currently apply only to land-based incineration.

1) *Require Air Pollution Control Equipment on Incinerator Ships.*—This is a major focus of the debate over ocean incineration, and reflects the major technical and regulatory diffference between land-based and ocean incineration. See chapter 1 for OTA's analysis of this issue.

2) *Require Secondary Chambers and/or Longer Residence Times on Incinerator Ships.*—EPA's initial proposal for regulating land-based incinerators under RCRA specified minimum operating conditions for residence time (how long the wastes must reside in the incinerator) and temperature. In promulgating its final regulations, however, EPA opted for what it considered a "more flexible" system based on performance standards. An exception to this approach is made for land-based incineration of PCBs regulated under the Toxic Substances Control Act (TSCA), which specifies minimum temperature and residence times.

EPA proposed an intermediate approach for regulating ocean incineration, to comply with international requirements under the LDC. Minimum temperatures would be required for the wall and flame of the incinerator, unless the trial burn established that DE and CE requirements could be met at lower temperatures. A minimum residence time (lower than that required under TSCA for land-based incineration of PCBs) would also be specified.

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[2] Marine water quality criteria have been developed for all 14 of the metals specified by EPA.

Critics of EPA's proposed ocean incineration regulation have argued that, relative to land-based incineration, ocean incineration technology is less safe because it employs a shorter residence time. Although not specifically required to do so, land-based rotary kiln incinerators are generally designed to include secondary chambers or afterburners, which expose volatilized waste to a second flame to ensure complete combustion. This design keeps wastes in the combustion zone longer, which is considered necessary for incinerating solids and sludges.

Liquid wastes, however, are often injected directly into the afterburner section of a rotary kiln, which means their residence time is relatively short. In addition, land-based liquid injection incinerators (like ocean-based incinerators) typically have no afterburner section. On land, therefore, liquid wastes generally are subject to shorter residence times than are solid or sludge wastes. Given the relative ease with which liquids are incinerated, short residence times may be sufficient for destruction.

Finally, as noted by the SAB (12), liquid injection incinerators on land and at sea generally employ higher temperatures than do rotary kilns. Generally, an inverse relationship exists between the residence time and the temperature required to attain a particular DE; that is, the higher the temperature, the shorter the time required to completely destroy the waste.

Thus, the important distinctions are not between land-based and ocean incineration, but rather between liquid wastes and solid and sludge wastes, and between liquid injection and rotary kiln technologies. A shorter residence time alone is not sufficient evidence of inadequate destruction of wastes.

Because residence time is primarily determined by the design of the combustion chamber or chambers, only limited increases in residence time are possible once a facility has been constructed. Therefore, the residence time of existing ocean incinerators could not be substantially lengthened.

Although considerable controversy over this issue has arisen in the debate over ocean incineration, EPA has maintained that relying on performance standards rather than design criteria ensures sufficient waste destruction, while providing flexibility and accommodating a variety of designs. Based on available information, this conclusion seems warranted.

Reducing Transportation Risks Associated With Ocean Incineration

Regulations governing hazardous waste transportation are scattered among numerous Federal agencies, and additional requirements often exist at the State and local levels. Although examining in detail the adequacy of the regulatory framework or coordination among various authorities exceeds the scope of this study, certain issues specifically related to ocean incineration can be identified and addressed.[3]

Current Controls

Transporting hazardous waste over land for the purpose of incineration at sea could involve the use of both highway and rail vehicles and would be subject to regulation primarily by the Department of Transportation (DOT). EPA's proposed ocean incineration regulation would not address land transportation activities. Instead, EPA argues, "controls imposed by programs specially designed and experienced in the area of land transportation are best able to provide protection against environmental risks during that phase of ocean incineration activities" (50 FR 8225, Feb. 28, 1985).

Waste transfer activities at port facilities would be subject to U.S. Coast Guard (USCG) regulations. EPA generally would defer to the USCG's special expertise and would not incorporate all USCG requirements into the permitting process for ocean incineration, although the USCG would have authority to recommend such permit requirements. EPA proposed that applicants for permits be required to prepare contingency plans detailing the procedures to be followed if spills occurred; the USCG would have review authority over the plans.

USCG regulations would also govern a ship's transit from the port facility to the incineration site. The USCG has authority to invoke several measures to ensure safe transit, including:

- providing a USCG escort and shiprider,

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[3] Another OTA assessment examines this issue in the context of transportation of hazardous materials in general (8).

- restricting transit to daylight hours or particular weather conditions,
- establishing a moving safety zone around the vessel, and
- requiring the vessel to broadcast a Notice to Mariners to avoid its route.

Imposing such measures falls under the jurisdiction of the Captain of the Port (COTP) and typically occurs as part of the permitting process, based on the COTP's evaluation of the particular conditions of each port. For the recently denied research burn in the North Atlantic, the COTP of Philadelphia incorporated all four measures into the research permit, which would have governed transit from the harbor to the open ocean.

The USCG is currently developing a set of instructions specifically for ocean incineration, designating a full range of measures (including those listed above) for COTPs to consider when determining what particular permits should require.[4]

Additional Controls

Two general approaches might address the problem of multiagency jurisdiction over ocean incineration activities.

Comprehensive Regulations.—Comprehensive regulations covering all aspects of ocean incineration could be developed under one agency (presumably EPA). The proposed Ocean Incineration Regulation obviously would not accomplish this bureaucratic feat, and EPA lacks the statutory authority to propose regulations that would. If the development of such regulations is desired, Congress would need to provide the necessary authority under the Marine Protection, Research, and Sanctuaries Act (MPRSA) or another statute.

Improved Regulatory Coordination.—A second, alternative approach would leave jurisdictions over distinct activities divided among various agencies, capitalizing on the USCG's particular expertise and experience, but would improve interagency coordination and would tailor regulations to the unique features of ocean incineration. Several steps in addition to those proposed by EPA would be necessary to accomplish this end.

1) *Cross-Reference Regulations.*—At a minimum, EPA regulations should specifically cite those regulations that, although promulgated and enforced by other agencies, would apply to ocean incineration.

2) *Clarify Regulatory Requirements and Jurisdictions.*—Regulatory requirements and agency jurisdictions would have to be clarified, perhaps by an Interagency Memorandum of Understanding, which some observers have recommended. Others believe, however, that because no actual conflicts exist between agency authorities or regulations, what would really be needed would be a clear guidance manual for agencies and the public. The manual would define agencies' authorities and responsibilities, cross-reference all applicable regulations, and state how the regulations applied to ocean incineration.[5]

3) *Develop Criteria for Selecting Ports.*—To govern or guide the selection of ports for ocean incineration activities, EPA should develop criteria analogous to those specified under the proposed regulation for selecting ocean incineration sites. These criteria should address the full range of factors that bear on using or developing a port facility, including such diverse issues as marine, highway, and rail traffic patterns; the nature and safety of access routes and their surroundings; the resources, capabilities, and emergency preparedness of local authorities; and the environmental sensitivity and economic value of areas that might be affected. Because so many topics would need to be considered, and because the potential exists for conflict with local governments that have authority over port development, the process of developing the criteria should involve all relevant Federal, State, local, and public interests.

Additional Regulatory Initiatives.—Both EPA and USCG are developing regulatory programs governing ocean incineration. Several specific aspects of these programs relating to transportation risks might require or warrant further attention to effectively address major public concerns.

1) *Designate Several Sites and Ports.*—Designating several ocean sites and port facilities for ocean incineration would help to reduce the distances

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[4] Commander C. Huber, U.S. Coast Guard, personal communication, June 1986.

[5] EPA is currently developing such a manual (13).

wastes would have to be transported, thereby reducing importation of wastes from other regions. The existence of several sites could at least theoretically increase public acceptance of ocean incineration, by lessening the risk any single community or region would have to bear, and by allowing wastes to be disposed of close to where they are generated. The major public opposition to using the Port of Philadelphia for a research burn in the North Atlantic as an alternative to the previously used Gulf Coast port and site, however, suggests that designating several sites might actually increase opposition by creating multiple "backyards."

2) *Tailor Waste Handling and Transportation Regulations Specifically to Ocean Incineration.*—The USCG is currently promulgating construction and design standards that would be specific for incineration vessels. Other USCG regulations, including requirements for certifying and operating waterfront facilities and for safely transferring bulk liquid cargoes other than oil, are more general in nature and may not be applicable to, or sufficiently account for, special problems associated with ocean incineration vessels and operations.[6]

Several technical or design features of the various existing and proposed ocean incineration technologies bear directly on transportation safety. These include containerization versus bulk storage and transfer, and self-propelled versus barge vessels (see ch. 6).

Incorporating Technological Improvements

Current Approach

In adopting a performance-based approach to regulating both ocean and land-based incineration, EPA established performance standards that reflect the capabilities of current incineration technologies to destroy waste and the detection limits of current sampling technologies. As EPA stated in its rationale for requiring a 99.99 percent destruction efficiency (a standard more stringent than that required under international law), "there is extensive data indicating that such destruction efficiencies are attainable and can be routinely measured in incinerators burning a wide range of organic wastes" (50 FR 8245, Feb. 28, 1985). Moreover, EPA argued that such an approach could both accommodate a broad spectrum of incinerator designs and maintain a high uniform level of performance.

The various existing and proposed technologies for ocean incineration differ in ways that could significantly affect the performance and safety of the incineration process itself, and of associated activities. Chapter 6 describes and compares these technologies in more detail.

The existence of alternative technologies creates a tension between two opposing approaches to regulatory policy. On the one hand, the regulatory framework must strive to incorporate superior design features that would allow performance standards to be upgraded, ensuring that such standards would not simply become the lowest common denominator. On the other hand, specifying particular design features in regulations might discourage the development of better designs and could render obsolete existing facilities that were designed to comply with standards regarded as sufficient at an earlier time. The latter phenomenon is typically addressed through "grandfathering" or by applying standards to new sources only.

Many observers have argued that existing incinerator ships represent "first generation" technology and should not be accorded the status of best available technology. Other observers disagree, arguing that, in addition to meeting all regulatory requirements, existing designs are "proven" technologies, in contrast to newer designs, which are either untested or lack sufficient operational experience.

Additional Approaches

EPA's proposed Ocean Incineration Regulation would not address the issue of how to incorporate better design features or to upgrade the performance standards for incineration vessels. Although many aspects of the problem extend well beyond this single regulation, certain steps could be taken to address its application to ocean incineration.[7]

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[6] The USCG is currently developing regulations that govern the handling and transfer of chemical substances; the regulations would be analogous to those that already apply to oil (Commander C. Huber, U.S. Coast Guard, personal communication, June 1986).

[7] Because none of these steps is required under RCRA, they would represent a departure from the approach used for regulation of land-based incineration.

Comparing Technologies.—Congress could require EPA to conduct a detailed comparison of the various existing, proposed, and emerging ocean incineration technologies, with respect to such factors as performance, cost, and availability. This evaluation should be ongoing or subject to periodic updating, in order to identify promising new research and development efforts.

Reviewing Permits.—The periodic review of permits for ocean incineration provides a natural point at which to consider whether additional regulatory requirements should be introduced or whether operating conditions or design features should be changed. EPA could institute such an evaluation as part of the permit review process.

Developing New Regulatory Approaches.—Congress could require EPA to examine the possibility of developing best available technology or new source performance standard approaches for regulating ocean incineration. Such approaches might provide means to increase the stringency of performance standards as technology capable of achieving them became available.

NONTECHNICAL ISSUES AND OPTIONS

Regulating Land-Based and Ocean Incineration Equitably

Current Approach

Land-based incineration facilities are regulated under RCRA (although incineration of PCBs is covered under TSCA), whereas ocean incineration vessels are regulated under the primary authority of MPRSA. Existing or proposed regulatory requirements for these two types of facilities differ in several ways, some of which are the subject of considerable controversy (see below).

The desirability of having different requirements for land-based and ocean incineration depends on numerous nontechnical factors, and therefore technical analysis alone generally cannot justify maintaining or eliminating the differences. For example, the shiprider requirement applicable only to ocean incineration may, in part, reflect the fact that public surveillance of incinerators would be much more difficult at sea than on land. This requirement therefore might be necessary to address the "out-of-sight, out-of-mind" concerns of the public and the regulator.

Clearly, equitable regulation of land-based and ocean incineration does not mean simply adopting identical sets of regulatory requirements. The technical and nontechnical bases for any differential regulations, however, should be thoroughly scrutinized and made as explicit and open to review as possible.

The issue of equitability raises larger questions concerning the adequacy of current legislative authority to regulate ocean incineration. Because it falls under MPRSA, ocean incineration is regulated as a form of ocean dumping. Although certain aspects of this activity (i.e., release of emissions directly into the marine environment) do constitute a form of ocean dumping, the fundamental purpose of the activity—waste destruction—might not be adequately addressed through MPRSA's legislative authority.

Regulatory Differences.—Listed below are requirements that apply exclusively to or are more stringent for one of the two technologies. Many of these requirements are discussed in detail in other sections of this report and are mentioned here only for the sake of comparison. Extensive rationales support many of the differences, so the more detailed discussions should be consulted for a full understanding of the issue.

Requirements That Apply Exclusively to or Are More Stringent for Land-Based Incineration.—At least three requirements apply only to land-based incineration or apply to it more stringently than to ocean incineration.

1. Emissions standards are specified for particulates and hydrogen chloride gas for land-based incinerators; no emission standards are specified for ocean incinerators, although environmental performance standards and mon-

itoring requirements that are not required of land-based incineration would be required for ocean incineration.

2. Air pollution control or particulate equipment is required for land-based incinerators if the emissions standards would otherwise be exceeded. Under TSCA, such equipment must be present if PCBs are burned.
3. For land-based incineration of PCBs, TSCA requires a minimum temperature of 1,200° C ± 100° C for a 2.0-second residence time, or 1,600° C ± 100° C for a 1.5-second residence time, with the temperature to be measured at the wall or flame of the incinerator. No operating conditions are specified for non-PCB wastes. For ocean incineration of all wastes, EPA proposes to require a minimum 1-second residence time and a minimum temperature of 1,250° C measured at the flame and 1,100° C measured at the incinerator wall.

Requirements That Apply Only to Ocean Incineration.—Several requirements apply to ocean incineration but not to land-based incineration:

- Waste analysis and operational monitoring data for each ocean burn would have to be submitted to EPA. Monitoring data would have to be recorded using an automatic tamper-resistant or tamper-detectable device.
- A limitation on metals content of wastes would be specified for ocean incineration but not for land-based incineration.
- Environmental monitoring would have to be conducted periodically during and following ocean incineration burns but not land-based incineration.
- EPA would have to review and approve the qualifications of ocean incineration company personnel involved in monitoring and analyzing waste.
- A full-time EPA shiprider, and possibly a USCG shiprider as well,[8] would be required to be on board for each ocean burn.
- Government inspection of ocean incineration vessels and port facilities (yearly by USCG, on demand by EPA) would be required.
- Transfer of wastes to the vessel at dockside would have to be supervised by the USCG.
- Each applicant for an ocean incineration permit would have to assess and report to EPA the potential effects of the applicant's loading and transportation activities on endangered species. EPA would have to prepare a formal endangered species assessment as part of the site designation process.
- As specified under MPRSA, each permit applicant would be required to demonstrate a need to incinerate wastes at sea.

Involving the Public in Decisions

Perhaps the major obstacle to developing a program of ocean incineration is the high degree of organized public opposition.[9] A full analysis of the historical and current basis for the opposition goes beyond the scope of this study; indeed, many of the issues raised in the public debate have broad application extending well beyond the confines of ocean incineration or even hazardous waste management. The importance of such issues in determining policy for ocean incineration, however, cannot be overstated.

Current Approach

Although EPA's fulfillment of the public hearing requirements set forth under MPRSA has provided for ample *expression* of public opinion, it has not succeeded in abating opposition or assuring the public of EPA's ability to develop an environmentally sound program. Moreover, although public opposition to incineration was a major factor in halting ocean incineration until regulations were promulgated, it is questionable whether the means that are available to EPA for ensuring public participation are capable of truly responding to public concerns.

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[8] This decision falls under the authority of the Captain of the Port, as discussed previously. At least for the initial burns, the USCG fully anticipates requiring a shiprider to accompany the vessel during harbor and bay transit.

[9] For an excellent discussion of the major areas of public concern and approaches to addressing them, see the recent EPA Hearing Officer's Report (13) and the accompanying Summary of Public Comments.

BROWNS-
VILLE
INTO
BURNS-VILLE
INCINERATE
THE
VULCANUS

Photo credit: Valley Morning Star, Harlingen, Texas

Over 6,000 people attended a U.S. Environmental Protection Agency public hearing held in Brownsville, Texas, in 1983. The hearing, which concerned whether a permit should be granted for incineration of PCB- and DDT-containing wastes in the Gulf of Mexico, was the largest public hearing in EPA history and reflected intense public concern about the technology.

Additional Approaches

Two general approaches have been suggested for addressing the issue of public opposition: first, mechanisms providing for greater or more meaningful public participation in decisionmaking; and second, measures for resolving specific issues of public concern.

Increasing Public Participation.—Several approaches would increase public involvement in decisionmaking, which could decrease opposition to ocean incineration:

- provide for public participation, through citizen advisory panels, in the permitting process and in selecting ports and incineration sites;
- develop national criteria or guidance for selecting ports in a manner that addresses public concerns and involves the public and local interests;
- develop a more explicit approach to involving State and local concerns in the decisionmaking process; and
- develop a broad waste management strategy and educate the public as to how incineration fits into it.

Resolving Specific Concerns.—Several approaches for resolving specific concerns warrant further attention:

- provide for adequate liability and public protection in the event of accidental spills or damages arising from incineration operations; in particular, provide adequate mechanisms for injured parties to recover damages;
- designate several ports and incineration sites to more equitably distribute the risks and burdens of ocean incineration;
- reopen the designation process for the Gulf Coast incineration site;
- carry out more research before proceeding with operational ocean incineration; and
- consider an applicant's compliance history in deciding whether to grant a permit.

VIEWING OCEAN INCINERATION IN A BROAD CONTEXT

The Effect of Ocean Incineration on the Development of Better Alternatives

Current Approach

Many critics of ocean incineration have argued that because ocean incineration would conceivably provide a cheap management option for liquid organic wastes, companies would choose ocean incineration instead of investing in waste reduction and recovery or better treatment technologies.[10] Proponents counter that ocean incineration would fill a niche by providing the best treatment option for wastes that do not, for economic or technical reasons, offer great potential for recovery or reduction.

OTA's analysis indicates that, for several reasons, ocean incineration would have a very limited effect on overall incentives for developing superior hazardous waste *management* practices:

- As the findings described in chapter 1 indicate, in the near future, only modest increases are expected in the use of recovery, recycling, and new treatment technologies for liquid organic hazardous wastes. These practices are expected to be applied mostly to nonincinerable wastes and would not be affected by the availability of ocean incineration as an option (see ch. 3).
- Only a small fraction (less than 10 percent) of all hazardous waste is suitable for ocean incineration, and the amount actually available for burning at sea would probably be significantly smaller, because of geographic, regulatory, and economic constraints. Realistic projections of the size of the market for ocean incineration indicate a small fleet of ships handling a very small fraction of all hazardous wastes.
- Predicting how future waste *reduction* activity would affect the ocean incineration market, and vice versa, is difficult because the necessary data are lacking and no meaningful way exists to measure waste reduction. Enormous potential obviously exists for such activity to significantly decrease the quantities of wastes requiring management; at least in the short term, however, major institutional, economic, and attitudinal obstacles to waste reduction remain.[11]
- Ocean incineration costs waste generators considerably more than do the other forms of management and disposal used for most incinerable wastes today. This cost differential might actually increase incentives for capital investment in recovery and reduction options, particularly when an economic return (even a relatively long-term return) on the investment could be anticipated.
- A portion of the ocean incineration market actually consists of wastes generated during the purification or recovery of chemicals (e.g., distillation wastes). These wastes, which can result from preferred management practices such as waste recovery, still require disposal or treatment, and are prime candidates for incineration.

Additional Approaches

Although ocean incineration would be unlikely to impede the development of better waste management practices in the current climate, Congress and EPA might want to ensure, for example, that incinerable wastes that were (or became) recoverable would be directed toward the best available management practices. Several policy directives or regulatory requirements that would specifically apply to users of ocean incineration might be considered that would make waste generators more accountable for properly managing their wastes.

Providing Accountability.—Precedent and a potential model for instituting accountability might already exist. The Ocean Dumping Regulations (40 CFR 227.14-227.16) explicitly require that each applicant for a permit to dump waste in the ocean must provide information on what processes generated the wastes, how it was previously disposed of, what other alternatives have been explored, and why the waste now needs to be dumped in the ocean.

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[10] The inadequacy of liability provisions for waste generators that choose ocean incineration also discourages better waste management, according to the critics. This issue is examined later in this chapter.

[11] Another OTA assessment, to be released in fall of 1986, explores these issues in detail (9).

Section 224 of the 1984 RCRA Amendments provides a step in the same direction for hazardous waste generators that dispose of wastes by methods regulated under RCRA. Although the effectiveness of regulations implementing Section 224 remains to be seen, the section is intended: 1) to require generators to develop waste reduction or detoxification programs on a waste-specific basis, and to report periodically on the progress of these programs; and 2) to certify on manifests that the treatment or disposal option to be used is "that practicable method currently available to the generator which minimizes the present and future threat to human health and the environment."

Applying such an approach to ocean incineration might be complicated by the fact that the permit applicants do not generate the waste but only transport and dispose of wastes that generally would come from numerous sources. Thus, evaluating and justifying the need to incinerate the wastes might be beyond the applicants' capabilities. This complication is one of the reasons that EPA's proposed Ocean Incineration Regulation would not require permit applicants to adhere to this requirement of the Ocean Dumping Regulations.

Nevertheless, operators of ocean incineration vessels could be required to gather waste-specific information from generators and submit it as part of their applications for permits. Such a requirement might, however, place the permit applicant in the difficult position of having to obtain data from potential clients and then wait for a determination from EPA before accepting or refusing the clients' wastes. Alternatively, waste generators seeking to use ocean incineration could be required, through regulatory provisions developed to address this aspect of the 1984 RCRA Amendments, to justify their need to use ocean incineration. Where appropriate, approval could be made contingent on compliance with a waste reduction schedule.

Directing Wastes to Better Alternatives.—Additional measures could include regulatory restrictions on the ocean incineration of wastes for which recovery or recycling capacity existed or could be developed. Economic approaches, such as imposing a tax on waste incinerated at sea, provide another possible avenue for ensuring that incinerable wastes would be directed toward preferred practices.[12]

Other less direct options might include measures to encourage the development and introduction of superior technologies for incinerable wastes. For example, Congress might consider providing direct incentives for research and development efforts and establishing a formal institutional structure for demonstrating new technologies. Such an approach might be especially useful for managing particularly troublesome wastes, such as PCBs.

Understanding the Impacts of Ocean Incineration Relative to Those of Other Alternatives

Many observers maintain that ocean incineration's possibilities and limitations in managing hazardous wastes have been inadequately defined and insufficiently exposed to public scrutiny and debate. This situation is one symptom of a much larger deficiency: **the lack of a comprehensive national hazardous waste management strategy.**

One of the major obstacles to developing such a strategy is the scarcity of comparative data on the potential effects and applications of available and emerging technologies. In the course of this study, OTA encountered major gaps in information about basic aspects of the waste management problem that greatly impede the development of sound policy. Congressional attention to several general problem areas might significantly strengthen our understanding of what a technology like ocean incineration can and cannot accomplish. Congress might want to:

- provide for more comparative research into waste management technologies by the Federal Government (e.g., by EPA and the National Oceanic and Atmospheric Administration), by industry (accomplished through incentives), and by universities (supported by Federal grants);

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[12] Unless it were applied to all waste management practices, or at least to those considered less environmentally sound than ocean incineration, such a tax might divert wastes to the less sound options.

- mandate and provide sufficient resources for establishing and maintaining more comprehensive and accessible databases on waste generation and disposal, number and status of management facilities, and numerous other basic areas; and
- ensure that current data-collection and monitoring efforts are designed, managed, and coordinated in a manner that generates useful and accessible information for use in decisionmaking.

OTHER ISSUES AND PUBLIC CONCERNS

In addition to the key policy issues discussed above, several other policy issues have become major public concerns in the debate over ocean incineration. This section describes and analyzes each of these issues and, wherever possible, highlights potential approaches to resolving them.

Demonstrating a Need for Ocean Incineration

Current Approach

Under provisions of both the London Dumping Convention and the Marine Protection, Research, and Sanctuaries Act, before a permit can be granted for the dumping of any waste at sea, the *need* for such dumping must be established. Because it falls under the definitions of ocean dumping used by both the LDC and MPRSA, ocean incineration would be subject to the requirement for a needs assessment.[13] The Eighth Consultative Meeting of Contracting Parties held in 1984 (cited in the preamble to the proposed Ocean Incineration Regulation; 50 FR 8247, Feb. 28, 1985) interpreted the need provision of the LDC to mean that:

> . . . other means of disposal should be considered in the light of a comparative assessment of human risks; environmental costs; hazards (including accidents) associated with treatment, packaging, transport, and disposal; economics (including energy costs); and exclusion of future uses of disposal areas, for both sea disposal and the alternatives. If the foregoing analysis shows the land alternatives to be more practical, a license for sea disposal should not be given.

The requirement to establish need has been incorporated into the proposed Ocean Incineration Regulation (Section 234.50) in a manner that EPA claims to be generally consistent with the LDC interpretation. Under the proposed regulation, need would not be defined solely in terms of capacity, so that even if sufficient land-based capacity existed, need for the ocean alternative could still be demonstrated: "Need will be presumptively demonstrated if ocean incineration poses less or no greater risks than practicable land-based alternatives" (50 FR 8247, Feb. 28, 1985).

EPA's proposed approach to demonstrating need is to prepare a *generic* needs assessment for ocean incineration on a national scale, rather than on a case-by-case basis.[14] The generic needs analysis would provide a rebuttable presumption of need for individual permit applications, placing on those who challenged permit applications the burden of proving that no need existed. EPA presented two rationales for such an approach:

1. The issue of ocean incineration is only a part of a larger problem of hazardous waste management, which requires solutions and management technologies to be looked at from a broad perspective far beyond the capabilities of the permit applicants.
2. The permit applicants do not generate the waste but only transport and dispose of waste that generally comes from numerous sources. Because applicants would lack the necessary information, evaluating and justifying the need to incinerate the wastes would be beyond their capabilities.

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[13] The requirement to establish a need for ocean incineration is a unique feature of the Marine Protection, Research, and Sanctuaries Act. Establishment of need is *not* required for land-based incineration or any other land-based waste disposal technology.

[14] EPA is apparently reconsidering its proposed generic needs approach in preparing its final Ocean Incineration Regulation, opting for the permit-by-permit approach embodied in the Ocean Dumping Regulations.

Additional Approaches

EPA's approach to defining need is emerging as a major point of contention in the ocean incineration debate. Critics of the technology argue: 1) that the burden of proof should lie with EPA to prove that ocean incineration is as safe as, or safer than, other available alternatives; 2) that need should be evaluated on a permit-by-permit basis; and 3) that the EPA's presumptive definition would be inconsistent with the intent of the MPRSA and LDC.

The controversy over the need for ocean incineration is in many respects related to the general issue of *accountability*. Public concern has been widespread that ocean incineration would largely free waste generators of accountability for wastes incinerated at sea. Accountability in this context would have two components: first, accountability for reducing wastes as much as possible (as initiated under the 1984 RCRA Amendments); and second, accountability with respect to legal liability for releases of waste. Implementing a mechanism for ensuring that generators would be held accountable would help to resolve the objections that ocean incineration would: 1) undermine incentives for waste reduction; and 2) allow generators to dispose of their waste with little or no liability, because of the difficulty of tracing waste back to its source or assigning liability to individual generators.

Setting Liability Requirements

Current Approaches

Many of the problems concerning liability that apply to ocean incineration reflect the much broader crisis in environmental liability generally. The growing difficulty in obtaining affordable commercial pollution liability insurance threatens all handlers of waste, hazardous and otherwise. Except as it directly relates to land-based and ocean incineration facilities, however, an analysis of liability is beyond the scope of this study.

At the outset, liability limits must be distinguished from financial responsibility requirements. Liability limits, which are commonly set by statutes, represent specified maximum amounts of money that parties can be legally required to pay for damages. Financial responsibility requirements, which can be set by statutes or regulations, are designed to assure that parties undertaking certain activities have sufficient financial resources to meet liabilities the parties might incur. Therefore, the liability limit and the required level of financial responsibility are commonly the same.

The MPRSA establishes no liability limits for any of the activities it covers, including ocean incineration; nor does the Act explicitly authorize EPA to impose a financial responsibility requirement through regulation. In the proposed Ocean Incineration Regulation, however, EPA indicated the clear need to impose such a requirement and solicited comments on an appropriate level of financial responsibility to be required of companies that seek to incinerate hazardous wastes at sea. EPA suggested a range of $50 million to $500 million (50 FR 8233, Feb. 28, 1985).

EPA's authority to impose any such requirement through its Ocean Incineration Regulation has been questioned (7), particularly because certain other statutes and regulations already apply to incineration vessels.

For purposes of comparison, the following discussion summarizes existing liability and financial responsibility requirements that apply to land-based and ocean incineration.

Land-Based Incineration.—Two Federal statutes invoke liability and financial responsibility requirements that apply to land-based hazardous waste treatment, storage, and disposal facilities, including land-based incinerators. RCRA sets "sudden and accidental" liability limits and financial responsibility requirements at $1 million per accident or $2 million annually. Limits for damages and third-party claims due to "gradual pollution" are higher: $3 million per incident or $6 million annually. The latter limits, however, currently apply only to landfills, surface impoundments, and land treatment facilities, not to incinerators. Further liability and financial responsibility requirements might be imposed on incinerators under regulations developed in response to RCRA's provisions for closure and corrective action, although these requirements would probably be determined on a facility-by-facility basis.

Superfund (formally known as the Comprehensive Environmental Response, Compensation, and Liability Act, or CERCLA) specifies a much higher liability limit of $50 million plus the costs of cleanup for some land-based hazardous waste treatment, storage, and disposal facilities, including land-based incinerators. (Corresponding regulations specifying levels of financial responsibility have not yet been developed under CERCLA, however, so land-based incinerators do not have to demonstrate their financial ability to meet the required level of liability. Given this, the applicable financial responsibility requirements are those specified under RCRA.)

Ocean Incineration.—EPA's proposed regulation was noncommittal on the issue of financial responsibility and solicited public comment on a proposed range of $50 million to $500 million for ocean incineration permittees.

Several existing statutory limitations, however, apply to incineration vessels (7). The oldest is based on maritime law, dating back to 1851, limiting the legal liability of vessel owners to the value of the vessel plus its cargo after the accident.

Congress has enacted two additional statutes that address liability as it applies to ocean incineration vessels.

Section 311 of the Clean Water Act.—This provision limits legal liability for pollution damages to $150 per gross ton, which amounts to $300,000 to $600,000 for existing incineration vessels. An identical financial responsibility requirement is specified.

Section 107 of the Current CERCLA.—This Superfund provision specifies a liability limit of $5 million to cover both damages to natural resources and the costs of responding to the release of a hazardous substance. The statute also imposes an identical financial responsibility requirement.

Thus, CERCLA's $5 million liability limit and financial responsibility requirement appear to represent the current limits applicable to ocean incineration vessels.

Additional Approaches

Recent amendments to CERCLA offered in both Houses of Congress (and agreed on in conference) would bring the liability limit for incineration vessels up to the level required of land-based incinerators, which is $50 million plus the cost of responding to the accident. In addition, the $50 million limit would apply to damages resulting from faulty incineration or other releases of waste, and would extend liability to the generators and transporters of the waste in addition to the vessel owners.

The amendments would also extend current financial responsibility requirements for land-based incinerators to ocean incineration vessels, but the exact amount of financial responsibility is not specified. Instead, the amendments provide EPA with the discretion to set financial responsibility requirements, with the explicit expectation that these requirements should be commensurate with those for other activities that have similar levels of risk.

If adopted, these amendments to CERCLA apparently would resolve the issue of whether EPA has the statutory jurisdiction to require liability insurance in excess of the limitations established under statutory law, or to invoke strict liability requirements for ocean incineration vessels.

Remaining Questions

Marine insurance policies are also subject to several legal defenses. For example, such policies typically do not cover damages resulting from acts of God. Most policies provide no coverage unless negligence by the vessel's owner or operator can be proved. Nor does coverage generally extend to damages resulting from the actual incineration process itself. In other words, coverage applies to damage arising from *sudden and accidental* events, such as spills, but not to damages from *gradual pollution*, such as incinerator emissions.[15] How such defenses and limitations would apply to releases from an ocean incineration vessel is currently an open question.

Another major remaining question concerns liability for damages to third parties. Critics have argued that existing law does not adequately provide for private parties to recover damages they have sustained from spills of hazardous substances. Proposed amendments to MPRSA would remove barriers to third-party suits, but they do not address the acknowledged difficulty third parties encounter in *collecting* damages.[16] Prospects for collecting damages are particularly slim when no evidence of direct physical damage can be offered, even though indirect or reputational damage may have been substantial. This issue is complicated by the extreme uncertainty entailed in estimating damages from hazardous waste spills.

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[15] Damages arising from *federally permitted releases* are excluded from coverage under CERCLA. This immediately raises the question of how to distinguish damage caused by permitted releases from damage caused by nonpermitted releases.

Availability and Costs of Liability Insurance

A major factor influencing the insurance market for incineration vessels is their lack of operating experience in this country. In addition, insurance is much more difficult to obtain and more expensive when coverage is desired for damages resulting from both the incineration function and the transportation function the vessels serve.

A recent study prepared for EPA assessed the market availability and potential costs of obtaining liability insurance for incineration vessels (1). Based on interviews with insurance industry representatives, the study estimated that coverage of $50 million would require a premium of about $5 million annually, or 10 percent of the liability limit. In contrast, a policy that meets the CERCLA-mandated $5 million liability limit would carry an annual premium of $20,000. The higher premium for incineration vessels could increase per-ton rates by as much as 63 percent, according to the study, and would make insurance costs the chief operating expense for ocean incineration.[17]

Evaluating the Effect of Ocean Incineration on Land-Based Incineration[18]

The Land-Based Perspective

Land-based incineration companies have strongly argued that ocean incineration is not needed, because the market for incineration of *organic liquid wastes* will not significantly increase (e.g., see refs. 2,6). They also argue that sufficient liquid waste incineration capacity already exists on land.

Moreover, these companies believe that *sludge and solid wastes* are best incinerated by using *high-energy* organic liquid wastes to provide the needed fuel, and they have suggested that the market for land-based incineration of sludges and solids, but not liquids, will increase. The companies have expressed concern that ocean incineration might draw off much of the available high-energy liquid waste, because of the economies of scale that the large at-sea incinerators would provide. If this occurred, the land-based incinerator companies would have to purchase raw fuel to burn sludges and solids, which they argue would be less cost-effective and less environmentally sound.

Land-based incineration companies base their views of future needs on the following analysis: Because liquid wastes are highly amenable to recovery or other treatment, the quantities of liquids available for incineration will decline, with a concomitant increase in quantities of sludges and highly viscous liquids which would result from the treatment and which could only be incinerated on land. These companies do not believe that the 1984 RCRA land disposal restrictions will greatly increase liquid waste volumes available for incineration, because most of the organic wastes currently landfilled are sludges and solids.[19]

The Ocean Perspective

On the other side of the issue, proponents of ocean incineration predict that the gap between capacity and demand for liquid waste incineration would continue growing if ocean incineration were not permitted. The proponents cite EPA's market analysis (10), which suggests this gap may be as high as sevenfold. This study is highly controversial, however, because of the myriad assumptions on which it is based (see ch. 3).

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[16] These amendments, to Section 106 of MPRSA, were adopted on June 26, 1986, by the House-Senate conference on H.R. 2005, which would reauthorize CERCLA (W. Stelle, House Committee on Merchant Marine and Fisheries, personal communication, July 10, 1986).

[17] These results have been disputed by some ocean incineration industry representatives. Based on their experience, these representatives argue that the costs and difficulty of obtaining liability insurance for ocean incineration are overstated.

[18] See ch. 3 for further analysis of the arguments presented here.

[19] This view appears to overlook liquids that are disposed in surface impoundments and deep wells. Some of these liquids could be incinerated. The use of these options also will be restricted under the 1984 RCRA Amendments, although at a slower pace than for landfills.

Ocean incineration companies believe that land-based incinerators are simply wary of the competition. High-energy liquid wastes form a very competitive market, in which land-based incineration companies already compete with industrial boilers and furnaces (e.g., cement kilns) as well as waste recyclers. Proponents of ocean incineration argue that land-based incinerators who want to continue to use liquid wastes as fuel for co-incinerating solids and sludges would only be able to obtain the liquid wastes by charging generators lower rates than those charged by their competitors. If land-based incinerators lost this market and had to resort to buying raw fuel, the costs could and would be passed on to the sludge and solid waste generators in the form of higher incineration charges.

Finally, proponents of ocean incineration argue that, in its absence, greater quantities of hazardous waste would be disposed of using land alternatives known to be unsafe, including illegal dumping, which would be far less acceptable than the potential risks posed by ocean incineration.

Designating Sites for Ocean Incineration

The proposed Ocean Incineration Regulation lists the Gulf of Mexico Incineration Site as the only currently designated site for ocean incineration and states that the site may be used for up to 10 years. Many members of the public and several elected officials, including the governors of two Gulf States, have argued that the designation process for the Gulf site should be reopened because conditions have substantially changed since its initial designation in 1976.[20] The changes include the discovery of valuable new fisheries in the area and increased ship traffic and navigational hazards. Questions have also arisen about the adequacy of opportunities for public participation in the initial decision and about whether EPA has complied with the Agency's own proposed criteria for site designation.

Finally, the 10-year designation has been challenged as too long a period to account for changing conditions and to accommodate any findings derived from environmental monitoring; an alternative proposal for 3-year designation with annual review has been proposed (for example, see ref. 16).

EPA has countered that the site still meets its initial selection criteria, and that it would also have to satisfy the new requirements for site designation (carrying capacity and a monitoring plan) before it could be used for operational burns.

The same issue has surfaced with respect to the proposed North Atlantic Incineration Site. An environmental impact statement (EIS) was prepared on the site in 1981, but changed conditions (including use of the adjacent 106-mile deepwater dumpsite for the dumping of sewage sludge) have led to requests that the 1981 EIS be updated (13). Updating the EIS for the Gulf site would also be warranted, given that it was initially designated in 1976 (see ch. 11).

Considering Applicants' Compliance Records

Current Approaches

Many concerned citizens and elected officials have suggested that an applicant's prior compliance record with Federal, State, or local environmental laws be included as a criterion in EPA's evaluation of applications for ocean incineration permits.[21] Texas has included such a provision in the State's new (and as yet untested) hazardous waste management act (16). EPA has rejected such proposals on the grounds that equitable criteria for such an evaluation are impossible to develop. As an alternative, EPA has proposed a permit-by-permit determination of an applicant's ability to meet all permit requirements and the development of an enforcement strategy to guide the response to a violation of a permit.

Additional Approaches

This issue is especially troublesome, because of its close link to the larger issue of public confidence in EPA and ocean incineration companies to carry out this program in the safest possible manner. At a minimum, EPA should evaluate whether the available means are adequate: 1) to ensure that applicants can (and do) meet all permit requirements, 2) to hold permittees fully liable for any damages that might result, 3) to enforce all provisions of the regulations, and 4) to provide for sufficient penalties for violations. It is also essential that the results of such a review be communicated to the public in an open manner.

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[20] A petition calling for the withdrawal of designation of the Gulf site has been submitted to EPA by Texas Rural Legal Aid (3).

[21] For a detailed discussion of this position and the precedents for its adoption, see ref. 4.

In addition, further attention should be given to developing appropriate means of considering the integrity and environmental compliance records of applicants for ocean incineration permits (13). Although a workable solution to this problem would be difficult to formulate, permit proceedings should at least provide full disclosure of applicants' records, including opportunities for applicants to explain relevant mitigating or changed circumstances. If, in preparing its final regulations, EPA ultimately decides to reject direct consideration of past compliance in evaluating permit applications, the rationale for the decision deserves more than the sort of passing mention provided in the proposed Ocean Incineration Regulation (50 FR 8248, Feb. 28, 1985).

Determining Appropriate Operating Permit Length and Renewal Provisions

Current Approach

EPA's proposed Ocean Incineration Regulation would grant operating permits for ocean incineration for 10 years, subject to renewal after 5 years (or more frequently at the request of the Assistant Adminstrator). Renewals would require approval of a new application and satisfactory completion of a new trial burn. EPA argues that shorter permit terms would not provide sufficient economic incentive for companies to enter the market or allow them to make sufficiently long-term commitments to waste generators (50 FR 8232, Feb. 28, 1985).

Additional Approaches

Although such concerns are legitimate, a permit length of 10 years at the initiation of a new program appears excessive. The length of the term is especially troublesome in light of the existing permit terms under other environmental regulations:

- a 3-year term for ocean-dumping permits under MPRSA;
- a 5-year term for discharge permits under the Clean Water Act;
- a requirement under the London Dumping Convention for a survey (including a trial burn) to be conducted every 2 years; and
- a 10-year term, with review every 5 years, for the well established land-based incineration program under RCRA.

Two provisions of the proposed regulations affecting permit renewal are also problematic. First, the review process appears to be limited to successful completion of a trial burn, and would not provide for reconsideration of the many factors that might have changed since initial granting of the permit: for example, the need for ocean incineration of the particular wastes to be burned; the environmental characteristics of the incineration site with respect to factors such as data obtained from monitoring, the presence of endangered species, or other or increased use of the site; and needed or desired changes in operating conditions, monitoring, or sampling protocols. Nor would the review appear to allow an opportunity to make more substantial changes as needed to reflect advances in ocean incineration technology or the scientific understanding of incinerator emissions, environmental impacts, and so forth. Particularly if a 10-year permit length were to be considered, a *substantive* review would be essential.

Second, as currently formulated, the proposed regulation would provide for continued operation beyond the end of the permit term in the event of a delay on the part of EPA in processing a permit reapplication. This provision is difficult to justify, given: 1) the small number of permits (and therefore, the relatively small administrative burden) likely to be involved; and 2) the real need for the criteria listed above to be reexamined prior to continued operation.

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Chapter 3

Incinerable Hazardous Waste: Characteristics and Inventory

CHARACTERIZING INCINERABLE WASTE

Waste Properties

Any discussion of the quantities of hazardous waste that could be incinerated on land or at sea must start by considering characteristics of both the waste and the technologies for incineration. This section identifies and discusses the most important characteristics of incinerable wastes, relating them to the requirements or restrictions of available incineration technologies.

Generally, only organic wastes or other wastes with significant organic content are considered appropriate for incineration, which excludes all inorganic materials.[1] Other important attributes of waste include energy content, physical form, the presence of hazardous constituents or properties, and chlorine and metal content.

Energy Content

An important characteristic that influences a waste's suitability for incineration is energy content (usually expressed in British thermal units, or Btu). Efficient thermal destruction of the organic portion of a waste requires that the entire mixture being incinerated have some minimum energy content. Therefore, many incinerable wastes must be blended with, or burned in the presence of, auxiliary fuel or high-energy waste to ensure complete destruction. Other incinerable organic wastes have sufficient energy content to maintain their own combustion, enhancing both the efficiency and cost-effectiveness of incineration.

Many common wastes represent mixtures of organic and inorganic materials. The organic fraction of such wastes, no matter how small, is at least technically incinerable. For example, the Environmental Protection Agency (EPA) recently used a mobile incinerator to destroy dioxin-tainted soil in Times Beach, Missouri. Four pounds of dioxin contained in 40 tons of soil were successfully destroyed by using auxiliary fuel to heat the soil to a sufficient temperature (20). However, for more routine operations, and particularly for commercial incineration, the cost of incinerating wastes with extremely low organic content would probably be prohibitive.

Physical Form

Different incineration technologies have developed for handling the various physical forms (solid, sludge, liquid, and gas) of hazardous organic wastes (see ch. 5).

Incinerable wastes that are candidates for ocean incineration generally fall into the category of *liquid* organic wastes. Only wastes in liquid form are suitable for the liquid injection technology used by all incineration vessels built or planned to date. Liquid injection technology has the advantage of large capacity but can only handle wastes that can be pumped and be introduced into the incinerator in the form of small droplets.[2]

A significantly broader range of waste forms is considered incinerable on land than at sea, because land-based facilities can employ a broader range of incineration technologies. Most commercial land-based incineration facilities use rotary kiln technology, which can incinerate organic *solids and sludges*, as well as liquids (25). Some existing rotary kilns can even incinerate solid waste contained in 55-gallon steel drums (1).

The presence of water in wastes can be either an advantage or a disadvantage with respect to their incinerability. Generally, aqueous (water-contain-

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[1] The term *organic* refers to chemical substances that possess a molecular skeleton made of carbon and hydrogen and that generally contain only a few other elements, such as nitrogen, oxygen, or chlorine. *Inorganic* materials are generally composed of or contain metals.

[2] Certain solid or sludge wastes that can be suspended in liquid waste to render them pumpable could also be incinerated at sea.

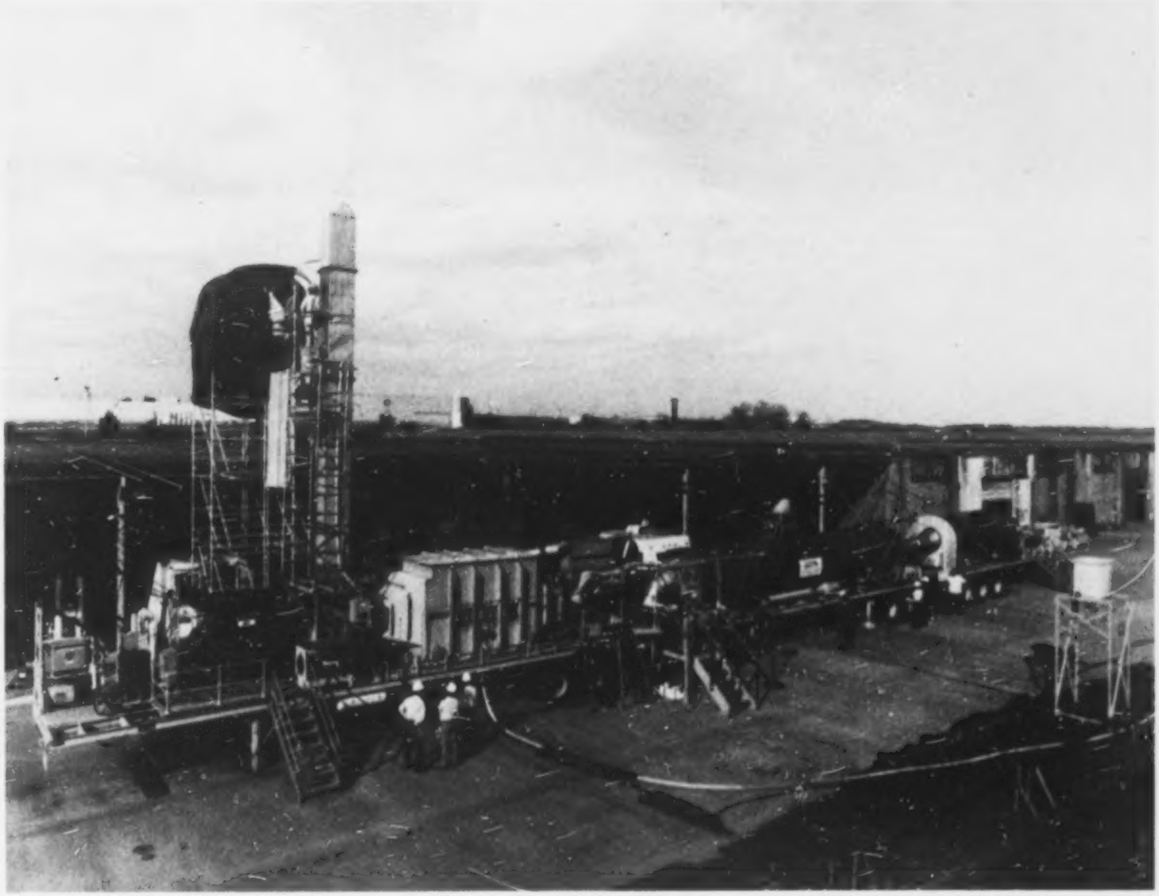

Photo credit: Air Pollution Control Association/EPA

A mobile incinerator, used by the U.S. Environmental Protection Agency to destroy wastes contaminated with dioxin. A mobile system can be transported to hazardous waste sites, thereby eliminating the need to transport wastes.

ing) wastes are not considered particularly amenable to incineration, because more energy is needed to heat and evaporate the water. If an aqueous waste also contains organic material with a very high energy content, however, the presence of water can actually prevent overheating and increase the rate at which wastes can be incinerated.

Hazardous Constituents or Properties

The vast majority of incinerable liquid wastes are subject to regulation as hazardous waste under the Resource Conservation and Recovery Act (RCRA) or certain State statutes. This designation may be based either on the presence of particular toxic components or on a generic characteristic of the waste (e.g., ignitability). In addition to incinerable wastes classified as hazardous, a few nonhazardous liquid wastestreams are amenable to incineration. For example, alcohol-based portions of some pharmaceutical and pesticide wastes are incinerable but not classified as hazardous (1).

Liquid organic wastes are derived from a wide variety of industrial processes and sources and, therefore, can contain an enormous number of chemical constituents. One profile undertaken by EPA identified over 400 distinct hazardous wastestreams being incinerated in land-based facilities (12). These wastes contained 237 different constituents, 140 of which were listed as hazardous under RCRA. Table 1 summarizes those constituents that were most commonly found and those that were incinerated in the greatest amounts.

A second EPA profile of existing hazardous waste incinerators used RCRA hazardous waste codes (40 CFR 261, Subpart D) to classify wastes currently being incinerated in land-based facilities. This study (10) found that the most frequently reported wastes were nonlisted ignitables (RCRA Code D001) with high energy content and high concentrations of hazardous constituents. The waste category representing the largest annual quantity of incinerated waste, however, was spent nonhalogenated solvents (F003). The next most common categories contained sufficient water to be considered *aqueous* wastes. These included the following:

- aqueous corrosives (D002),
- aqueous reactives (D003),
- aqueous ignitables (D001) with low energy content and low concentrations of hazardous constituents,
- wastewater from acrylonitrile production (K011), and
- hydrocyanic acid (P063).

Most of these aqueous wastes are considered poorly suited for recycling and recovery and are generated in quantities too large to be economically shipped for offsite disposal. Therefore, the wastes are generally managed—by using underground injection or, where possible, incineration—at the facilities where they were generated. Such wastes would be unlikely candidates for ocean incineration.

Table 1.—Most Common and Most Abundant Chemical Constituents Found in Incinerated Hazardous Wastestreams

Five most commonly identified constituents	Five constituents incinerated in the greatest amounts
1. Toluene	1. Methanol
2. Methanol	2. Acetonitrile
3. Acetone	3. Toluene
4. Xylene	4. Ethanol
5. Methyl ethyl ketone	5. Amyl acetate

SOURCE: Mitre Corp., *Composition of Hazardous Waste Streams Currently Incinerated*, contract report prepared for the U.S. Environmental Protection Agency, Office of Solid Waste (Washington, DC: April 1983).

Chlorine Content

Many liquid wastes considered especially amenable to ocean incineration contain relatively high amounts of organically bound chlorine.

Energy content is inversely related to chlorine content, which means that the heat value of wastes decreases as chlorine content increases.

Thermal destruction of chlorinated wastes by incineration generates highly corrosive and toxic hydrogen chloride gas. Land-based facilities are required to have air pollution control equipment (i.e., scrubbers) capable of removing and neutralizing acid gases, if wastes with significant chlorine content are to be incinerated (47 FR 27520, June 24, 1982). The proposed Ocean Incineration Regulation (50 FR 8222, Feb. 28, 1985) does not require the use of scrubbers on ocean incinerator vessels, because of seawater's natural capacity to neutralize hydrogen chloride gas, and because the vessels operate far away from human populations.[3]

Several factors act to place a practical limit on the chlorine content of wastes that can be incinerated in land-based facilities, as discussed in chapter 1. These factors include:

- limitations on the practical size and capacity of scrubbers for removing hydrogen chloride gas;
- the increase in the quantity and corrosivity of hydrogen chloride emissions as the chlorine content of wastes increases, which can damage the incinerator or scrubber system; and
- the generation of chlorine gas (13,28), which is not efficiently removed by stack scrubbers and could pose risks from direct inhalation by nearby human populations.

For these and other reasons, the chlorine content of hazardous wastes can strongly influence the range of available management options. Wastes of intermediate chlorine content can in some cases be burned in cement kilns and other industrial furnaces, where corrosive gases are directly used in the production process. Although there appears to be an enormous available capacity for burning such wastes in these facilities, the reluctance of many furnace operators to use the wastes as fuel, the relative lack of regulation and rigorous environmental testing of the practice, and practical limits on acceptable chlorine content, are obstacles to its greater application (2,5,17). See chapter 4 for a detailed discussion of the burning of hazardous wastes in industrial boilers and furnaces.

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[3] For a number of reasons, incineration of highly chlorinated wastes at sea may be advantageous (see ch. 1).

Metal Content

In contrast to the organic component of hazardous wastes, metals are not destroyed by incineration. Metals present in waste fed to an incinerator are either deposited in the ash residue left behind in the chamber or emitted in stack gases. Most metals that leave the incinerator stack are in the form of particulate matter and can be captured by stack scrubbers.[4] Particulates and associated metals are deposited in the sludge generated by the operation of the scrubber. Ash and sludge residues from hazardous waste incineration are generally classified as hazardous waste and must be handled accordingly.

Although metals are not destroyed by incineration, high temperatures can alter the physical and chemical forms of metals, thereby affecting their subsequent fate and behavior. For example, certain toxic metals (e.g., arsenic and selenium) are volatilized (i.e., changed into gas form) during incineration and pass through particulate collection devices (28). For this reason, wastes that contain significant amounts of these toxic metals or that have high overall metal content are not considered appropriate for incineration.

Types of Ocean-Incinerable Wastes

Liquid organic wastes are derived from a wide variety of industrial processes and sources. These include activities or uses that: 1) contaminate materials so that they are no longer usable in the process (e.g., spent solvents); 2) produce wastes through purification or recovery of desired products (e.g., distillation wastes resulting from solvent recovery or chemical synthesis); 3) produce wastes through treatment or handling of other wastes (e.g., PCB contamination of solvents used to clean electrical transformers); or 4) result in products that do not meet specifications and therefore must be discarded.

Four major categories of liquid hazardous wastes are generally identified as primary candidates for ocean incineration. These categories, their RCRA classification designations, their primary uses, and their industrial sources are listed in table 2. Special materials or wastes, such as liquid PCBs, are also candidates for ocean incineration. These wastes, which are unique in many respects, are discussed in box B. The four major liquid incinerable waste categories are briefly described below (1).

Waste Oils

These result from the use of lubricants, greases, and other petroleum specialty products. Waste oils are used in a variety of ways because of their high heat content and relative ease of reclamation. Waste oil can be: 1) burned as fuel in boilers and furnaces; 2) used as auxiliary fuel for incineration; 3) re-refined for reuse in its original purpose; or 4) used for dust suppression on roads (a declining practice because of environmental concerns).

A well established and growing market for the reuse of waste oils exists, along with a network for the collection of waste industrial and commercial transportation oils. Collection and reuse of waste automotive oils from individuals is not yet an established practice but is on the rise. As indicated in table 2 and discussed further in chapter 4, waste oils are coming under RCRA regulation as hazardous waste. These regulations have the potential to affect the quantities of such wastes available for incineration.

Nonhalogenated Solvents

Waste solvents are commonly generated as mixtures of solvents, including aromatic hydrocarbons, ketones, alcohols, and esters. Many waste solvents contain large amounts (10 to 50 percent) of water, as well, although this is increasingly avoided through process modifications. The wastes also typically contain significant amounts of suspended solids, including organic and inorganic pigments and heavy metals (lead, chromium, barium, copper, nickel).

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[4] Particulate matter may be composed of metals adsorbed onto dust or soot particles, or actual small metallic fragments. Particulate matter can vary significantly in size, and small particles are captured much less efficiently by air pollution control equipment than are large particles (1).

Table 2.—Major Categories of Ocean-Incinerable Hazardous Waste

Type of waste	RCRA classification	Primary uses	Major sources
Waste oils	[a]	Industrial lubricants Transportation oils	Metal and service industries
Nonhalogenated solvents	D001, F003-005	Painting, coating, cleaning operations	Manufacturing
Halogenated solvents	F001-002	Cleaning and degreasing agents	Manufacturing Dry cleaning
Other organic liquids	"K wastes"	Generated in chemical production	Organic chemicals manufacturing

[a] Waste fuel and used oil fuel are coming under RCRA regulation as a result of the 1984 amendments. EPA has proposed listing used oil as a hazardous waste (50 FR 49528, 29 November 1985), and has finalized regulations for burning of waste fuel and used oil fuel in *nonindustrial* boilers and furnaces (50 FR 49164, 29 November 1985). Burning of waste fuel and used oil fuel in *industrial* boilers and furnaces is currently exempted from regulation, although EPA plans to regulate this practice under permit standards to be proposed in 1986.

SOURCE: Office of Technology Assessment.

Nonhalogenated waste solvents are generally in demand as fuel because of their high heat content (greater than 10,000 Btu/lb). In addition, large quantities of waste solvents are currently cleaned through distillation for recycling or reuse.

Halogenated Solvents

Most halogenated[5] solvents consist of chlorine-containing compounds, with bromine- and fluorine-containing compounds much less common. Waste halogenated solvents are produced in the cleaning and degreasing of metals, machinery, and garments, and hence commonly contain oils, greases, dirt, and other solids. The dry cleaning industry generates substantial quantities of waste perchloroethylene.

Halogenated solvents have a high initial economic value due to the expense of their production and, therefore, are commonly recovered through distillation for reuse. Most halogenated solvents are not in demand as fuel, because they have relatively low heat value (less than 5,000 Btu/lb). In fact, their incineration often requires the use of auxiliary fuel.

Other Organic Liquids

A broad range of wastestreams with significant organic content is generated by various industrial processes used to manufacture or purify organic chemicals. Typically each of the wastestreams is homogeneous but may have a unique composition. Many or most wastestreams created in chemical production or purification are specifically listed as hazardous wastes under RCRA, and are referred to as "K" wastes. The wastestreams can contain a very broad spectrum of hazardous constituents. Organic, water, and halogen content, and thus heat value, can also vary significantly.

Several techniques are available or being developed for separating the organic and aqueous fractions of these wastestreams, potentially allowing greater or more economical use of incineration for destroying the organic portion. Although organic wastes mixed with water can be incinerated, the energy requirements (and hence costs) of doing so often increase dramatically as water content increases. However, for a waste whose organic portion has a very high energy content, the presence of water can actually be used to advantage by reducing total heat output to avoid overheating of the incinerator.

QUANTIFYING INCINERABLE WASTE

Waste Inventory

The absolute quantities of incinerable waste may not adequately reflect the degree of *toxicity or hazard* associated with a particular waste type. For example, many industrial wastewaters are composed of extremely dilute aqueous solutions of hazardous chemicals. In contrast, many incinerable wastes are among the most concentrated and toxic of all haz-

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[5] Halogens are a group of related chemical elements, which are present in many organic chemical compounds. The group includes fluorine, chlorine, bromine, and iodine.

Box B.—PCBs: A Unique Hazardous Waste Problem

The management and disposal of wastes containing polychlorinated biphenyls (PCBs) is in many respects a unique hazardous waste problem. Indeed, PCBs have become a focal point of policy and regulatory attention, even though the total quantity of PCB wastes represents a tiny fraction of all hazardous wastes generated annually in the United States. The strong concern about these chemicals is based on: 1) increases in our understanding of their extreme persistence in the environment, their toxicity to humans, and their ability to bioaccumulate in living organisms; 2) the discovery of massive PCB contamination at land and marine sites previously used for their disposal; and 3) their ubiquitous occurrence that has resulted from widespread industrial use.

The term *PCBs* refers to a group of some 200 related chemical compounds manufactured between 1929 and 1977, primarily by Monsanto under the trade name Aroclor (3). These compounds possess properties of fire- and heat-resistance, low electrical conductivity, and extreme chemical stability, which made them ideal as insulators in electrical transformers and capacitors.[6]

Unlike most other hazardous wastes, PCBs represent a historical waste because they are no longer manufactured in the United States. Congress called for specific and strict regulation of PCBs in passing the Toxic Substances Control Act (TSCA) in 1976, and EPA banned further U.S. production in 1979 (44 FR 31514, May 31, 1979). More recently, EPA instituted a schedule for the eventual phasing out of all remaining electrical equipment employing PCBs (50 FR 29170, July 17, 1985).

Quantities of PCBs

EPA estimates that 200 million pounds of PCBs remain in use in the United States today. Most (about 160 million pounds) are contained in electrical equipment owned by utility companies (see ref. 6; also see 47 FR 17426, Apr. 22, 1982). The table below shows the distribution of utility PCBs between transformers (which can be opened, drained, and refilled with other insulating fluid) and capacitors (which are permanently sealed). Under new EPA rules, utilities must phase out the use of PCB transformers in or near buildings by 1990 (50 FR 29170, July 17, 1985).

Equipment type	*Number of utility-owned units*	*Pounds of PCBs*	*Percentage of utility PCBs*
PCB transformers	40,000	75,000,000	45.92
Large PCB capacitors	2,800,000	88,000,000	53.90
Mineral oil transformers	20,200,000	262,000	0.16

PCB concentrations in the insulating fluids contained in transformers and capacitors are estimated to average roughly 15 to 20 percent (26), which means that the 200 million pounds of PCBs still in use may actually be contained in some 1 billion to 1.3 billion pounds (450,000 to 600,000 metric tons) of fluid. In addition, replacement of PCBs in transformers is accompanied by cleaning with solvents, which, once contaminated with PCBs, are the source of an additional large but unknown quantity of PCB-contaminated waste. Thus, the great majority of PCB and PCB-contaminated wastes is in *liquid* form.

Current Regulation and Disposal of PCBs

Regulations developed under TSCA distinguish three classes of PCB-containing materials (40 CFR 761.3). Materials that contain PCB concentrations greater than or equal to 500 parts per million (ppm) must be disposed of through incineration in facilities meeting TSCA requirements (40 CFR 761, Subpart D). Materials that contain PCB concentrations of 50 to 500 ppm may be incinerated, or under certain conditions, disposed of in chemical waste landfills[7] or destroyed in certified high-efficiency boilers. Materials containing fewer than 50 ppm of PCBs are not subject to TSCA disposal requirements, and may therefore be incinerated in RCRA-approved facilities, under conditions that are less stringent than those required for the first two classes of PCB-containing materials.

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[6] PCBs were also used in the manufacture of paper, plastics, adhesives, lubricants, inks, lamps, and hydraulic fluids.

[7] Nine landfills currently have permits for PCB disposal. These facilities only accept PCBs in solid form, in anticipation of prohibitions on landfilling of liquid wastes contained in the 1984 RCRA Amendments (18).

In addition to the above disposal and treatment options, a few chemical and biological treatment methods for PCBs have recently received approval.[8] These methods, however, currently can be applied only to wastes with relatively low concentrations (less than 500 ppm) of PCBs (18); they are likely to be particularly useful for cleaning up past disposal sites, which often occurs onsite using mobile units.

Under current regulation, incineration is the only widely applicable technology permitted and available for destroying *liquid* PCB wastes, particularly those with high PCB concentrations. At present, six land-based incineration facilities are approved for incineration of high-level PCBs.[9] EPA permit data from 1984 indicate that these facilities had an annual capacity for some 54,000 metric tons of PCBs, equivalent to roughly 300,000 metric tons of PCB-containing wastes (26). While the great majority of this waste is in liquid form, the cleanup of PCB disposal sites is expected to generate solid PCB wastes as well.

An EPA survey of commercial hazardous waste facilities, including three commercial facilities permitted for PCBs (ENSCO, SCA, and Rollins), indicated that nearly 420,000 metric tons of PCB wastes (almost exclusively liquid) were received in 1984 (8). This data, coupled with reports of several-month backlogs for incineration of PCB liquid wastes (26), indicates a current shortfall in incineration capacity for PCBs. The extent and duration of the shortfall will largely depend on how quickly current electrical equipment is phased out and how much capacity is developed in alternative technologies. Estimates of how long the demand for PCB incineration will substantially exceed capacity typically range from 3 to 10 years, although if additional restrictions are placed on the use of landfills and boilers for disposal of PCB-contaminated material, this period might be lengthened significantly (8,26).

Reasons for Concern Over the Treatment and Disposal of PCBs

The adequacy of the current methods that are used to manage PCB wastes has been the focus of considerable public attention and concern, which is certainly justified in light of the special character of the wastes. Several additional unique features regarding the transport and incineration of PCBs warrant special consideration:[10]

- Because PCBs are no longer commercially produced, they are not routinely transported in commerce, except as waste. This is in contrast to most other liquid incinerable hazardous wastes, which are commonly transported in much greater quantities as *pure* chemicals. The transport of PCBs for incineration thus would **not** simply represent an incremental increase in risk over that associated with routine commercial transport, as would be the case for most other ocean-incinerable wastes (see ch. 8).
- Of the various candidates for ocean incineration, PCBs are among the most environmentally persistent, and they have the greatest potential to be accumulated by exposed organisms and thereby introduced into the food chain. PCBs are of *intermediate toxicity* relative to other candidates for ocean incineration (7).
- Regulations require that PCBs be incinerated with a higher destruction efficiency than that required for most other wastes. Although this would greatly reduce emissions, verification of this greater destruction efficiency presents a considerable challenge to our current analytical and sampling methods. Indeed, the achievement of a high destruction efficiency during past U.S. burns of PCBs at sea could not be demonstrated, because of limits in *sampling* capability, not because of any demonstrated shortcoming in the incineration process itself (see ch. 11).

Use of Ocean Incineration for PCBs

Both international and proposed domestic regulations applicable to ocean incineration give special consideration to PCBs. For PCBs and a few other compounds,[11] international regulations developed under the

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[8] Companies that have recently received permits for such methods include DeTox, Acurex, Chemical Decontamination Corp., and SunOhio.

[9] Five of these facilities are owned and operated by ENSCO in Arkansas, Rollins Environmental Services in Texas, SCA Chemical Services (now owned by Chemical Waste Management) in Illinois, Pyrotech in Tennessee, and General Electric in Massachusetts. The GE facility is used for both private and commercial purposes (26). The sixth incinerator is EPA's transportable unit, currently in New Jersey. A seventh incinerator—a transportable unit being built by GA Technologies—also recently received a permit.

[10] This discussion is equally applicable to consideration of both land-based and ocean incineration of PCBs.

[11] The other compounds include DDT, polychlorinated terphenyls (PCTs), TCDD (dioxin), and benzene hexachloride. Much of the ensuing discussion in this section also applies to wastes containing these substances.

London Dumping Convention (LDC) require that an incinerator's ability to achieve sufficient destruction of the compounds be demonstrated through trial burns, due to "doubts as to the thermal destructibility" of these materials (50 FR 8228, 28 February 1985; see ref. 9 and also see ch. 7). In addition, in the United States, existing land-based incineration regulations and the proposed Ocean Incineration Regulation specify a more stringent destruction efficiency standard for PCBs than for other wastes (see ch. 7). Finally, the special requirements of TSCA would apply to the ocean incineration of PCBs. These requirements include separate approval from the Assistant Administrator of the Office of Pesticides and Toxic Substances.

Although allowed under international law, ocean incineration of PCBs has not routinely occurred. Two at-sea burns of PCB wastes have taken place. In 1982-83, wastes of Australian origin were burned in the Pacific Ocean (see ch. 12); in 1981-82, U.S. wastes were burned in the Gulf of Mexico under an EPA research permit (see ch. 11).

A diversity of opinions and approaches exists in the international community regarding the potential use of ocean incineration for PCB wastes. For example, the Federal Republic of Germany specifically prohibits ocean incineration of PCB wastes. Recently, however, The Netherlands announced plans to conduct an at-sea trial burn of PCB wastes, in anticipation of a possible need for this option as a result of the loss of previously used land-based PCB incineration capacity (see ch. 12).

Photo credit: Fred Ward, © 1985 National Geographic Society

Polychlorinated biphenyls (PCBs) were primarily used as insulators in electrical equipment, such as these capacitors that are being stored in a Japanese warehouse until a method for final disposal is decided upon.

ardous wastes and, therefore, represent a much larger fraction of the total toxicity attributable to hazardous wastes than their absolute quantity indicates.

Total Hazardous Waste

Given that virtually all ocean-incinerable wastes are classified as hazardous, the starting point for estimating the quantity of such wastes is to examine the various inventories for hazardous waste generation. Unfortunately, no statistically reliable database exists to allow an accurate estimation of the total generation of hazardous wastes. Studies vary tremendously both in the definition of what constitutes hazardous waste and in methodologies for data collection and analysis. In addition, all the studies rely to some extent on sets of simplifying assumptions and models. Although using such assumptions is probably essential for generating a complete national profile, they represent another major and inherent source of variability and uncertainty.

The most prominent (and most often cited) of such studies is the so-called Westat mail survey, which was completed for EPA's Office of Solid Waste in April 1984 (27). The Westat study estimated that 264 million metric tons (equivalent to 71 billion gallons) of hazardous waste were generated in the base year of 1981. This quantity is many times larger than all previous estimates and is generally regarded to be far closer to the actual quantity.

The Westat figure closely agrees with estimates made by the Congressional Budget Office (21) for the base year of 1983, using industrial output models (see below), and by the Office of Technology Assessment (23) for the base year of 1981, using data obtained from a survey of the States. This agreement is somewhat surprising, in view of the fact that the Westat survey was primarily designed to determine numbers of waste generators and treatment, storage, and disposal facilities, rather than waste quantities.

Incinerable Hazardous Waste

Virtually all of the available national data on hazardous waste generation are aggregated by broad industrial categories, rather than by specific waste types. Consequently, the data are not useful in estimating the portion of hazardous waste that is incinerable. Moreover, even the basis for defining a material as a *waste* is often far from clear. For example, solvents are not always classified as waste if they have the potential to be recovered. And many States do not consider used oils as waste and therefore do not require them to be recorded on manifests, which means estimates of incinerable quantities must be extrapolated from available data on oil use and recovery (1).

Finally, many ill-defined technical, economic, and regulatory limitations bound the universe of incinerable wastes. These and other constraints greatly hinder an accurate measure of how much incinerable hazardous waste is generated annually.

This section discusses two studies that allow an estimation of waste generation by waste type and therefore help to bound estimates of the quantity of incinerable waste. **With respect to wastes suitable for ocean incineration, these studies suggest that between 10 million and 21 million metric tons (mmt) of liquid incinerable wastes are generated on an annual basis in the United States.**

A recent study by the **Congressional Budget Office (CBO)** (21) can be used to provide an upper estimate of incinerable waste quantities. This study estimates national generation of hazardous waste in a manner that allows aggregation of the data under any of four classifications: 1) by Standard Industrial Classification (SIC) codes representing major industrial categories (e.g., chemicals and allied products); 2) by waste type (e.g., halogenated liquids); 3) by method of treatment or disposal (e.g., deep-well injection); or 4) by State. Data derived from EPA survey estimates (27) for a base year of 1983 are used to make projections for the year 1990.

The hazardous waste universe as defined by CBO is significantly larger than that currently regulated under RCRA. In particular, the CBO definition includes waste oils, which are only now being brought under RCRA regulation; PCBs, which are regulated under the Toxic Substances Control Act (TSCA); and industrial scrubber sludges, air pollution control dusts, and certain other liquid hazardous wastestreams, which EPA is currently studying for possible future regulation under RCRA.

Several additional features of the CBO study warrant discussion, as they introduce some uncertainty into the resulting estimates of waste generation. Because comprehensive and statistically reliable *raw* data on which to base waste generation estimates were generally lacking, CBO developed a computer-based model of hazardous waste generation derived from data on industrial output for 70 industrial categories.[12] This approach assumed that specific industries generated particular types of waste at measurable rates. These generation rates were assumed to result from three factors: industrial output (measured by employment directly related to production, on an industry-by-industry basis), process technology, and production efficiency. Estimates of *future* waste generation were then derived from projections of growth in industrial employment. CBO found that statistics on employment growth were the only comprehensive and consistent set of industry-specific projections available. Because such statistics only indirectly reflect waste generation, however, a degree of uncertainty was introduced into the resulting estimates (21).

In addition to attempting to account for changes in waste generation resulting from changes in industrial output, CBO also estimated changes due to the application of waste reduction, recycling, and recovery practices. CBO's projected estimates of the levels of *recycling and recovery* that could be expected by 1990 were based on information obtained directly through surveys of industrial waste generators and the waste recovery industry. These estimates were then applied to the waste generation estimates, which were derived using the CBO model.

Estimating the future extent of waste *reduction* is extremely difficult, given the current lack of data and the absence of an accepted and appropriate means of measuring waste reduction (24). For this reason, CBO's analysis did not consider the full range of approaches that might be used to reduce waste. CBO's estimates, therefore, probably understate the potential for reduction. However, although an enormous amount of waste reduction is possible, many obstacles remain (24).

Despite these potential shortcomings, the CBO effort represents the *only* available source of comprehensive waste generation data that is aggregated on the basis of specific waste types, which is essential for estimating quantities of *incinerable* wastes.

Given its limitations, the CBO data may be best used to derive an upper estimate of incinerable waste generation. Waste generation data are first aggregated by waste type to allow estimation of the quantities of waste generated in those categories that could be managed through incineration. These data are then adjusted downward to account for the levels of recycling, reuse, and recovery that currently take place in each waste category, as estimated by CBO. Finally, separate aggregation of data for liquids versus solids and sludges provides an estimate of quantities of waste that are ocean-incinerable (liquids) and waste that could only be incinerated on land (solids and sludges). Table 3 presents the estimates derived using such a procedure.

The numbers presented in table 3 should be taken as an *upper bound* for the following reasons:

- It is unlikely that all of the wastes in each category are physically or economically suitable for incineration.
- Current market factors dictate the use of less expensive disposal practices (e.g., underground injection) even for clearly incinerable wastes.
- Other competing fuel uses, particularly for wastes with high energy content, reduce quantities available for incineration.
- Many incinerable wastes are extensively recovered, reused, or recycled (see column 2 in table 3), and the application of such practices is growing due to clear economic incentives.
- Application of other treatment methods (e.g., chemical detoxification of PCBs) and waste reduction practices to some incinerable wastes is likely to increase in the near future.

Even with these limitations, the CBO data indicate that large quantities of the hazardous waste generated annually could be incinerated, either on land or at sea. This upper estimate indicates that as much as 47 mmt per year, or about one-fifth of all hazardous wastes not currently recovered or recycled, could be incinerated. As much as 21 mmt

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[12] These 70 industries accounted for about 95 percent of all hazardous waste generated in 1981, according to the Westat survey (27).

Table 3.—Quantities of Incinerable Wastes Generated in the United States, 1983

Type of waste	Quantity generated (mmt)	Current percent RECYC/RECOV[a]	Quantity after RECYC/RECOV[a] (mmt)
Liquids:			
Waste oils	14.25	11%	12.68
Halogenated solvents	3.48	70	1.04
Nonhalogenated solvents	12.13	70	3.64
Other organic liquids	3.44	2	3.37
Pesticides/herbicides	0.026	55	0.012
PCBs	0.001	0	0.001
Total liquids	33.33	38%	20.74
Sludges and solids:			
Halogenated sludges	0.72	0	0.72
Nonhalogenated sludges	2.24	0	2.24
Dye and paint sludges	4.24	0	4.24
Oily sludges	3.73	5	3.54
Halogenated solids	9.78	0	9.78
Nonhalogenated solids	4.58	0	4.58
Resins, latex, monomer	4.02	65	1.41
Total sludges/solids	29.31	10%	26.51
Total incinerable wastes	62.64	25%	47.25
Total hazardous wastes	265.60	6%	249.28

All quantities are millions of metric tons (mmt).

[a] RECYC/RECOV refers to waste recycling and recovery practices that affect the quantity of waste needing treatment or disposal. These estimates are derived by CBO from information obtained directly through surveys of industrial waste generators and the waste recovery industry.

NOTE: All other categories listed by CBO are inorganic liquids, sludges, and mixed or solid wastes, with low or no potential for incineration.

SOURCE: Office of Technology Assessment, based on U.S. Congress, Congressional Budget Office, *Hazardous Waste Management: Recent Changes and Policy Alternatives* (Washington, DC: U.S. Government Printing Office, 1985); and unpublished data.

per year are liquids that could be incinerated on land or at sea. In contrast, only an estimated 2.7 mmt—slightly more than 1 percent of all hazardous waste generated in the United States and less than 6 percent of all wastes that could have been incinerated—were incinerated in 1983 (21).

Table 3 indicates that very different quantities of the four major categories of ocean-incinerable waste were generated. CBO estimated that waste oils and nonhalogenated solvents were generated in amounts about four times higher than were halogenated solvents and other organic liquids. After accounting for current levels of recycling, however, waste oils were predominant, and waste halogenated solvents represented the smallest category.

A second study, conducted under contract to OTA, provides a lower bound on the quantities of incinerable hazardous wastes generated nationally on an annual basis. **Arthur D. Little, Inc.** (1) has developed estimates of *liquid* organic hazardous wastes based primarily on data derived from biennial State hazardous waste reports to EPA for the year 1983. These data were aggregated by RCRA hazardous waste codes (40 CFR Part 261, Subpart D) but also include additional wastes considered hazardous under State regulations.

The ADL estimates provide a *lower bound* on the quantities of incinerable hazardous waste, for the following reasons:

- The ADL inventory included only those RCRA categories designating wastes that were essentially 100 percent incinerable, including
  —D001 (ignitable wastes),
  —F001-F002 (halogenated solvents), and
  —F003-F005 (nonhalogenated solvents).
- The inventory excluded several other categories that contain potentially significant quantities of incinerable wastes, because the incinerable fraction could not be estimated. Excluding these categories undoubtedly means a significant underestimation of total incinerable waste quantities. The categories include:
  —D002 (corrosive wastes),
  —D003 (reactive wastes),
  —K wastes (wastes from specific sources),

  - —P wastes (wastes containing acutely hazardous compounds), and
  - —U wastes (wastes containing toxic compounds).
- Certain wastes that were managed onsite were specifically excluded from the State reports. These include wastes burned as fuel in industrial boilers and wastes recycled at the facilities where they were generated. Many such wastes are not required to be reported as waste under existing regulations.
- Data that could be used to determine quantities of incinerable liquid wastes generated in 1983 were not available for six States.[13]

ADL's lower bound estimate for the quantity of incinerable liquid wastes in these categories (which exclude waste oils) is 5.8 mmt annually. This can be compared to the somewhat higher CBO estimate of 8.1 mmt (see table 3).

The ADL analysis also included an examination of the use and disposition of waste oils. Of the estimated 2.1 billion gallons annually used in the United States, ADL estimated that about 1 billion gallons are consumed in use, leaving 1.1 billion gallons currently divided between disposal and various forms of reuse (burning as fuel, reclamation, asphalt conditioning, and dust control). This quantity is equivalent to about 4.2 mmt of waste oil annually, which is significantly lower than the 12.7 mmt of waste oil estimated by CBO. The reasons for this large discrepancy are unclear. Both studies, however, estimated that waste oils constitute just over 40 percent of all liquid wastes generated.

In sum, ADL conservatively estimated that a minimum of about 10 mmt of incinerable *liquid* waste suitable for ocean incineration is generated annually in the United States.

Industries Generating Incinerable Waste

Most incinerable waste is generated by a few major industries. CBO has estimated the amounts of various waste types contributed by industries in each of 12 SIC codes representing major industrial classifications (U.S. Congress, Congressional Budget Office, unpublished data). For each of the four major categories of incinerable liquids, figure 1 shows the industries that together contribute over 90 percent of the wastes. With respect to *total* hazardous waste generation, the list includes industries that are major (chemicals and petroleum/coal) and minor (wood preserving and motor freight transportation) contributors (21).

Geographical Distribution of Waste Generation

For both total and ocean-incinerable hazardous wastes, CBO's data allows an estimation of generation rates for 1983 on a State-by-State basis. A regional distribution profile for hazardous waste generation can be developed by adding the estimates for the States comprising each EPA Region. Table 4 presents such a regional profile, and table 5 lists the 10 States in which the most ocean-incinerable hazardous waste is generated. Figure 2 shows the proportion of ocean-incinerable wastes generated by each State in the Nation.

As is apparent from figure 1, the great majority of ocean-incinerable hazardous wastes is generated by the petroleum and chemical industries. Figure 2 indicates, not surprisingly, that at least half is generated along either the Gulf Coast (primarily from petroleum refining) or the Middle Atlantic Coast (primarily from chemical industries).[14] These conclusions are consistent with a comparable analysis performed for OTA using data submitted by the States to EPA in their biennial reports (1).

Thus, a large portion of ocean-incinerable waste would not have to be transported great distances to reach potential ocean incineration port facilities. Moreover, this geographical distribution is consistent with EPA's designation of an ocean incineration site in the Gulf of Mexico, and its proposal for a site located off the Middle Atlantic Coast.

Projections of Future Waste Generation

Projections of future generation of hazardous waste and of liquid organic hazardous waste require the use of assumptions that can drastically affect the resulting estimates. One common approach to formulating such projections, therefore, is to design a number of scenarios based on various reasonable sets of assumptions, in the hope of at least bounding the problem. However, estimates derived by such an approach carry a degree of uncertainty that render their use in a policy setting problematic. Given existing deficiencies in the data on which projections must be based, uncertainty is an inherent problem that must be borne in mind when considering any projection of waste generation.

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[13] The six States were Arizona, Colorado, Kansas, Oklahoma, Utah, and Wyoming. None of the six are coastal States, and all but two (Kansas and Oklahoma) are expected to be very minor producers of incinerable wastes.

[14] According to the CBO data, Texas alone produces nearly one-quarter of all such liquid wastes (see table 5).

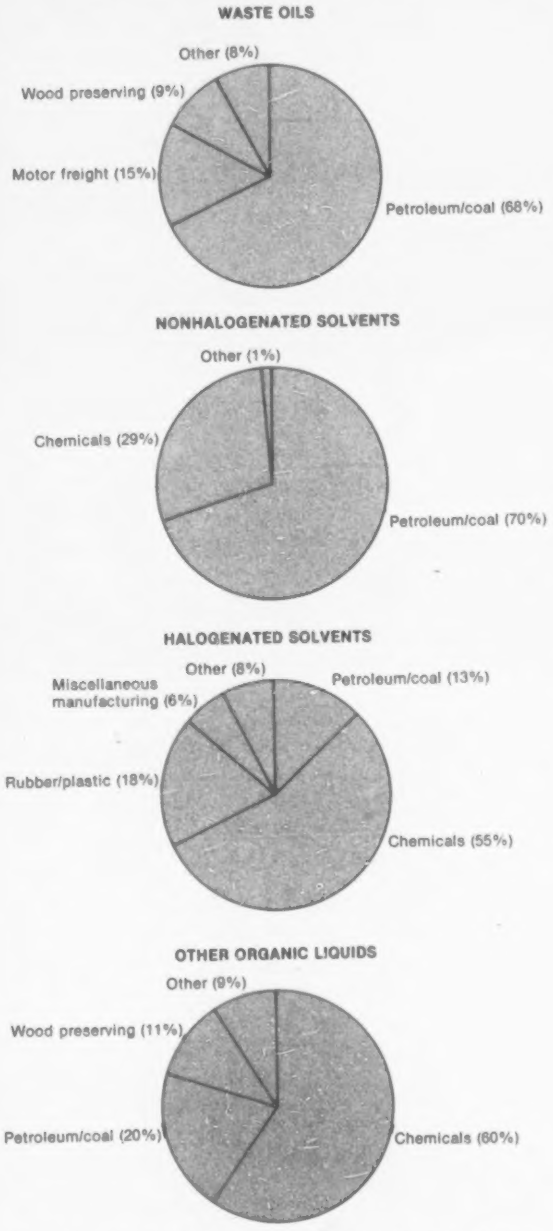
Such projections must also reflect recent changes in the regulatory environment surrounding hazardous waste management. As a result, many additional data gaps and sources of uncertainty are introduced. For example, in adjusting estimates to account for the effect of the land disposal restrictions contained in the 1984 RCRA Amendments (22), assumptions are required about the schedule and extent of their implementation and the anticipated responses of generators and handlers of affected wastes.

The **Congressional Budget Office** (21) has estimated the quantity of hazardous waste that will be generated and that will require disposal or treatment in 1990. These projections, which are aggregated by waste type, can be compared with the quantities generated in 1983. The projections assume that EPA will meet the land disposal deadlines specified in the 1984 RCRA Amendments, which are scheduled to be largely implemented by that time.[15]

CBO's projection model takes into account two additional variables that could significantly influence the quantities of wastes requiring disposal or treatment in 1990:

1. the extent and effect of waste recovery and recycling activities undertaken by industry;[16] and

Figure 1.—Major Industries Generating Wastes Suitable for Ocean Incineration



SOURCE: Office of Technology Assessment, based on U.S. Congress, Congressional Budget Office, *Hazardous Waste Management: Recent Changes and Policy Alternatives* (Washington, DC: U.S. Government Printing Office, 1985); and unpublished data.

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[15] CBO indicates that this assumption is perhaps overly optimistic but that any other assumption would be arbitrary. To the extent that the implementation schedule is delayed, use of undesirable land practices will continue. Moreover, many of the specified deadlines are contingent on availability of capacity in alternative treatment technologies.

[16] As indicated previously, CBO has not attempted to account for the full extent of waste *reduction*, because of information on which to base such an analysis is unavailable.

Table 4.—Generation of Ocean-Incinerable and Total Hazardous Wastes, by EPA Region, 1983

EPA region	States	Total hazardous wastes	Percent of total	Ocean-incinerable hazardous wastes	Percent of total
I	CT, MA, ME, NH, RI, VT	11.51 mmt	4.3%	0.78 mmt	2.3%
II	NJ, NY	22.83	8.6	2.45	7.4
III	DE, MD, PA, VA, WV	31.82	12.0	2.76	8.3
IV	AI, FL, GA, KY, MS, NC, SC, TN	39.11	14.7	3.16	9.5
V	IL, IN, MI, MN, OH, WI	62.60	23.6	5.54	16.7
VI	AR, LA, NM, OK, TX	55.69	21.0	11.75	35.4
VII	IA, KA, MO, NK	11.12	4.2	1.39	4.2
VIII	CO, MT, ND, SD, UT, WY	4.70	1.8	1.18	3.6
IX	AZ, CA, HI, NV	18.51	7.0	3.41	10.3
X	AK, ID, OR, WA	7.71	2.9	0.79	2.4
	Totals	265.60 mmt		33.22 mmt	

SOURCE: Office of Technology Assessment, based on U.S. Congress, Congressional Budget Office, *Hazardous Waste Management: Recent Changes and Policy Alternatives* (Washington, DC: U.S. Government Printing Office, 1985); and unpublished data.

Table 5.—Top 10 States for Generation of Ocean-Incinerable Hazardous Waste, 1983

State	Quantity (mt/yr)	Percent of all ocean-incinerable hazardous waste
Texas	7,723,175	23.2%
California	3,199,166	9.6
Louisiana	2,468,357	7.4
Pennsylvania	1,846,652	5.6
Illinois	1,782,197	5.4
New Jersey	1,674,352	5.0
Ohio	1,304,503	3.9
Oklahoma	1,051,550	3.2
Indiana	977,969	2.9
Michigan	805,882	2.4
		68.6%

SOURCE: Office of Technology Assessment, based on U.S. Congress, Congressional Budget Office, *Hazardous Waste Management: Recent Changes and Policy Alternatives* (Washington, DC: U.S. Government Printing Office, 1985); and unpublished data.

2. changes in baseline waste generation due to expected increases or decreases in the production activities of particular industries, in response to both general and industry-specific economic factors.

Thus, for a given waste category, each of the above factors contributes to any changes predicted to occur between 1983 and 1990.

Expected changes in total hazardous waste generation and in individual waste categories are presented in tables 6 and 7. The summary in table 6 presents CBO's data for the broad categories of incinerable wastes (liquids versus solids and sludges) and nonincinerable wastes, and indicates how both waste recycling/recovery and changes in waste output affect the projected net change in waste quantities. Table 7 presents a more detailed examination of CBO's data aggregated by individual waste type.

Two major trends are apparent from these data. First, CBO predicts that waste recovery and recycling activities will only modestly decrease the quantities of potentially *incinerable* wastes. As shown in column 8 of table 6, the greatest effect of waste recovery and recycling will be on *nonincinerable wastes*. These data predict that the decrease in amounts of nonincinerable wastes due to increases in waste recovery and recycling activities will be almost 15 times greater than the decrease in incinerable *liquids* (44 mmt versus 3 mmt). A few particular waste types, such as metal-containing liquids, will account for a large portion of the decrease in nonincinerable wastes (see table 7).

This trend becomes even more apparent when the actual quantities of wastes expected to be recovered or recycled in 1990 are compared with the figures for 1983 (table 6). For *nonincinerable wastes*, almost 45 mmt is projected to be recovered or recycled in 1990, whereas less than 1 mmt is estimated to have been recovered or recycled in 1983. However, the projection for *incinerable wastes* is about 20 mmt for 1990, only a modest increase over the 15 mmt recovered or recycled in 1983.[17]

A second trend indicated by these data is that the two factors discussed above—changes in waste generation and the limited application of waste re-

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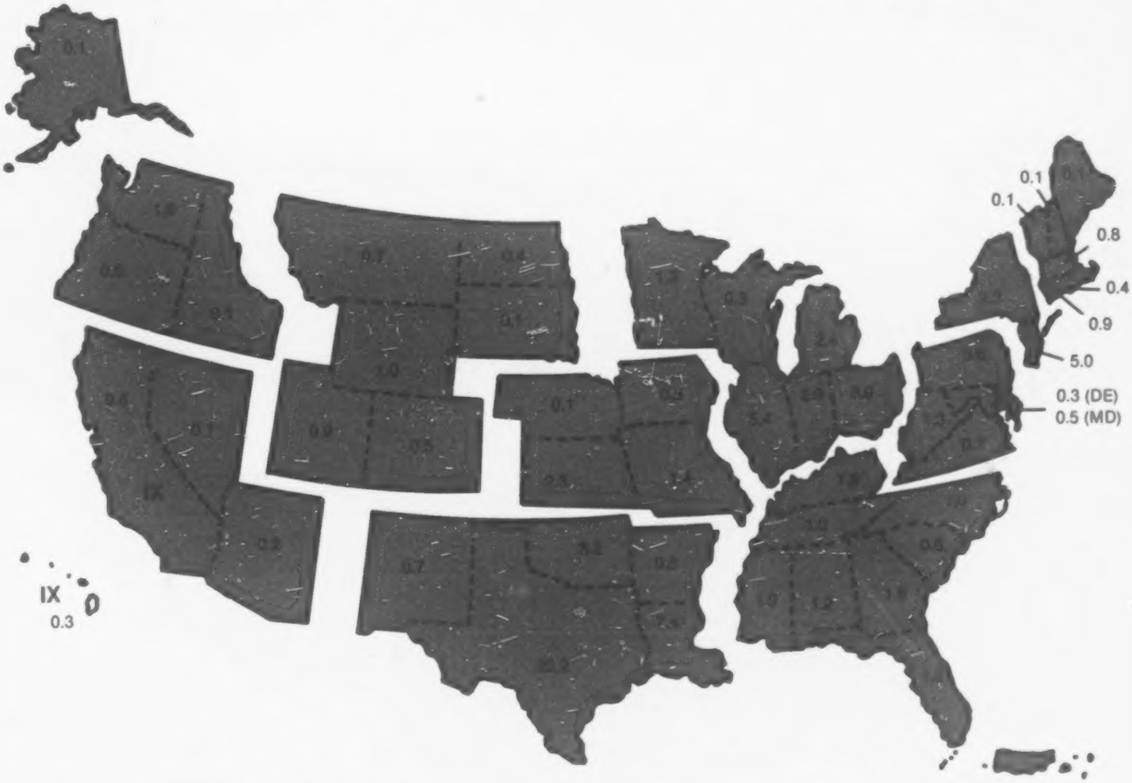
[17] These figures are calculated from the data in table 6 as follows: for 1990, subtract column 5 from column 4; for 1983, subtract column 2 from column 1.

Figure 2.—Percent of Total Ocean-Incinerable Hazardous Wastes Generated by State, 1983



SOURCE: Office of Technology Assessment; based on U.S. Congress, Congressional Budget Office, *Hazardous Waste Management: Recent Changes and Policy Alternatives* (Washington, DC: U.S. Government Printing Office 1985), and unpublished data.

covery and recycling to incinerable wastes—will both slightly alter the relative amounts of liquids versus solids and sludges generated in 1990. The CBO data (table 6, column 9) predict that the quantities of incinerable solids and sludges will slightly increase between 1983 and 1990 (by about 1 mmt), whereas the quantity of incinerable liquids will slightly decrease in quantity (by about 3 mmt). *Despite these changes, CBO projects that waste in both categories will continue to be generated in quantities that greatly exceed our current incineration capacity for them.*

Several other sources, including evaluations of future hazardous waste management needs undertaken by a number of States, support the conclusions drawn from this analysis of the CBO data. Two of the sources will be discussed here to lend further support to these conclusions.

The **Minnesota Waste Management Board** (11) projected that, because of economic growth, Minnesota's generation of wastes in 14 representative categories would increase substantially by the year 2000, even under the State's "high waste reduction alternative." This scenario assumed that wastes would be reduced as much as possible and recycled whenever they had resource recovery potential. Estimates of the extent of waste reduction[18] expected in each category by the year 2000 were

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[18] In the Minnesota study, the term waste reduction is broadly applied to include recovery and recycling activities as well as source reduction.

Table 6.—Hazardous Waste Generation in 1983 and 1990: Effect of Recycling and Recovery on Waste Quantities Requiring Treatment or Disposal, Summary of Comparison

	1983			1990			Change in quantity, 1983 to 1990[a]			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Type of waste	Quantity generated (mmt)	Quantity after RECYC/RECOV[b] (mmt)	Percent waste RECYC/RECOV[b]	Quantity generated (mmt)	Quantity after RECYC/RECOV[b] (mmt)	Percent waste RECYC/RECOV[b]	Change in quantity generated (mmt)	Change due to waste RECYC/RECOV[b] (mmt)	Change due to both factors (mmt)	Total percent change[c]
Incinerable wastes:										
Liquids	33.33	20.74	38	33.39	17.80	47	+0.06	−3.00	−2.94	−14.2
Sludges/solids	29.31	26.51	10	32.20	27.61	14	+2.89	−1.79	+1.10	+4.2
Total	62.64	47.25	25	65.59	45.41	31	+2.95	−4.79	−1.84	−3.9
Nonincinerable wastes	202.96	202.03	<1	214.77	169.98	21	+11.81	−43.86	−32.05	−15.9
All hazardous wastes	265.60	249.28	6	280.36	215.39	23	+14.76	−48.65	−33.89	−13.6

[a] Changes occurring between1983 and 1990 are due to two factors: waste recycling/recovery and changes in baseline waste generation. *Both* factors are reflected in this table. For example, examine the entries in the table for incinerable liquids. Comparing the middle columns for 1983 and 1990, there is projected to be a net decrease in incinerable liquid wastes of 2.94 mmt (this is listed in column 9). However, not all of this change is due to waste recycling/recovery activities. Columns 7 and 8 show that the change is due to a slight *increase* in the amount of waste generated (column 7, +0.06 mmt), plus a *decrease* due to waste recycling/recovery (column 8, −3.00 mmt). Negative (−) signs indicate a decrease in waste quantity. Positive (+) signs indicate an increase in waste quantity.

[b] RECYC/RECOV refers to waste recycling and recovery practices that affect the quantity of waste needing treatment or disposal. These estimates are derived by CBO from information obtained directly through surveys of industrial waste generators and the waste recovery industry.

[c] This percentage is calculated as follows:

$$\text{Total percent change} = \frac{\text{1990 quantity after RECYC/RECOV} - \text{1983 quantity after RECYC/RECOV}}{\text{1983 quantity after RECYC/RECOV}} \times 100$$

SOURCE: Office of Technology Assessment, based on U.S. Congress, Congressional Budget Office, *Hazardous Waste Management: Recent Changes and Policy Alternatives* (Washington, DC: U.S. Government Printing Office, 1985); and unpublished data.

Table 7.—Hazardous Waste Generation in 1983 and 1990: Effect of Recycling and Recovery on Waste Quantities Requiring Treatment or Disposal, Comparison by Individual Waste Type[a]

	1983		1990		
Type of waste	Percent waste RECYC/RECOV	Quantity after RECYC/RECOV (mmt)	Percent waste RECYC/RECOV	Quantity after RECYC/RECOV (mmt)	Percent change in quantity after RECYC/RECOV 1983-1990
Incinerable wastes:					
Liquids:					
Waste oils	11%	12.68	15%	11.84	−6.6%
Halogenated solvents	70	1.04	80	0.76	−26.9
Nonhalogenated solvents	70	3.64	80	2.37	−34.9
Other organic liquids	2	3.37	25	2.82	−16.3
Pesticides/herbicides	55	0.012	70	0.008	−33.3
PCBs	0	0.001	0	0.001	0.0
Total incinerable liquids	38	20.74	47	17.80	−14.2
Sludges and solids:					
Halogenated sludges	0	0.72	0	0.68	−5.6
Nonhalogenated sludges	0	2.24	0	2.48	+10.7
Dye and paint sludges	0	4.24	25	3.08	−27.4
Oily sludges	5	3.54	10	3.20	−9.6
Halogenated solids	0	9.78	0	11.56	+18.2
Nonhalogenated solids	0	4.58	0	5.23	+14.2
Resins, latex, monomer	65	1.41	70	1.38	−2.1
Total incinerable sludges/solids	10	26.51	14	27.61	+4.2
Total incinerable wastes	25	47.25	31	45.41	−3.9
Nonincinerable wastes:					
Metal liquids	2	19.36	70	5.99	−69.1
Cyanide/metal liquids	2	7.24	75	1.82	−75.0
Nonmetallic liquids	0	82.26	20	71.93	−12.6
Metal sludge	0	14.50	10	13.63	−6.0
Cyanide/metal sludge	0	0.56	15	0.50	−10.7
Nonmetallic sludge	0	28.06	5	26.77	−4.6
Contaminated soils	0	5.46	0	5.75	+5.3
Metal dusts/shavings	5	7.34	15	6.90	−6.0
Nonmetallic dusts	0	21.12	10	19.99	−5.4
Explosives	0	0.72	5	0.78	+8.3
Miscellaneous wastes	0	15.41	5	15.92	+3.3
Total nonincinerable wastes	<1	**202.03**	21	**169.98**	−15.9
All hazardous wastes	6	**249.28**	23	**215.39**	−13.7

[a] See footnotes to table 6 for explanation of table.

SOURCE: Office of Technology Assessment, based on U.S. Congress, Congressional Budget Office, *Hazardous Waste Management: Recent Changes and Policy Alternatives* (Washington, DC: U.S. Government Printing Office, 1985); and unpublished data.

used to predict the annual quantity of waste that would require treatment or disposal. Table 8 provides these projections for several categories.

The data from the Minnesota analysis support the conclusions drawn by the CBO study:

- a net increase will occur in future quantities of incinerable wastes, including liquids, even after accounting for waste reduction;
- the application of waste reduction, recycling, and recovery practices will be greater for nonincinerable wastes than for incinerable wastes; and
- substantial quantities of *both* organic solids/sludges and liquids will require treatment into the foreseeable future.

The **New Jersey Hazardous Waste Facilities Siting Plan** (5) estimated the effect of waste reduction on the quantities of various types of hazardous wastes that are sent offsite for treatment or disposal. Baseline quantities were projected for 1988, and then adjusted to account for the anticipated extent of waste reduction. Table 8 shows the data for several major categories of incinerable and nonincinerable hazardous waste.

Table 8.—Two State Estimates of Future Hazardous Waste Generation and Extent of Waste Reduction (all quantities in thousands of metric tons)

	Minnesota		
	Baseline projection for 2000	Downward adjustment for waste reduction	Net change in quantity over 1982
Incinerable:			
Solvents/organic liquids	33	−7	+7
Oils and greases	75	−22	−3
Organic sludges/bottoms	8	0	+2
Nonincinerable:			
Inorganic liquids/sludges	42	−28	−17
All hazardous wastes	212	−66	−13

	New Jersey		
	Baseline projection for 1988	Downward adjustment for waste reduction	Net change over average quantity for 1981 to 1983
Incinerable:			
Organic liquids	95	0	+35
Solvents	34	−4	+2
Oils	69	−3	+5
Nonincinerable:			
Inorganic liquids	122	−21	−6
All offsite waste	418	−30	+41

SOURCES: Minnesota Waste Management Board, 1984; and Environmental Resources Mangement, Inc., *New Jersey Hazardous Waste Facilities Plan*, prepared for New Jersey Waste Facilities Siting Commission (Trenton, NJ: March 1985).

This analysis of data for New Jersey wastes sent *offsite* also supports the same general conclusions as the CBO study: most waste reduction will be applied to nonincinerable wastes, and even after accounting for such activity, large and increasing quantities of incinerable (as well as nonincinerable) waste will require treatment.

Onsite Versus Offsite Management of Hazardous Wastes

Another important distinction to be made in discussing quantities of waste likely to require treatment or disposal is whether waste management activities occur within the facility at which wastes were generated (*onsite*), or at a separate, typically commercial, facility (*offsite*). Each of these waste management strategies poses its own special advantages, requirements, and risks. For example, offsite management introduces the added burdens of transportation and recordkeeping, although inspection and enforcement are generally accomplished more easily at offsite facilities.

Whether a waste generator decides to manage its wastes onsite or offsite largely depends on the size of the generator. Some generators can realize economies of scale sufficient to make investment in onsite facilities attractive, and others generate wastes in quantities too large to make offsite transport practicable; small generators typically find it more cost-effective to ship wastes to commercial facilities for treatment or disposal. **The onsite versus offsite distinction is especially relevant to ocean incineration, which is by definition offsite.**

The majority of all hazardous waste is disposed or treated onsite, although available estimates vary over a considerable range. The Westat survey (27) and the CBO study (21) estimated that less than 5 percent of all hazardous waste was managed or disposed of offsite. Interestingly, a number of State or regional analyses found that a somewhat larger proportion was managed offsite. For example, Minnesota's data indicated that at least 15 percent of its hazardous waste was managed offsite (11). Two New Jersey studies reached disparate estimates: One study (5) suggested that only a small percentage of all waste was sent offsite;[19] the other (28) indicated that 26 percent of New Jersey's hazardous waste was sent for offsite disposal or treatment. A recent study of hazardous waste management in New England found that the region's waste was divided almost evenly between onsite and offsite management (14).

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[19] If wastewater were excluded from this calculation, an estimated 25 percent would be sent offsite.

Unfortunately, none of these data concerning on/offsite distribution was aggregated by waste type, which precludes a separate evaluation for those wastes with potential for incineration at sea. However, other data suggest that most liquid organic hazardous wastes are managed onsite. The Westat survey (27) found that about 0.9 mmt of liquid organic hazardous wastes was incinerated in land-based facilities in 1981, and that 98 percent of this activity took place onsite. And the EPA market analysis (26) found that at least 90 percent of current incineration of liquid wastes took place in private onsite facilities.

Current land-based incineration of all forms of hazardous waste follows a similar distribution: In 1983, 210 to 250 onsite hazardous waste incinerators managed an estimated 2.4 mmt, and about 30 offsite incinerators managed about 0.4 mmt (2,10, 19,21).

Considerable uncertainty surrounds projections of onsite versus offsite waste management and, more specifically, incineration. It is not known whether, and to what extent, waste generators facing restrictions on land disposal options will choose (or will be able) to develop additional onsite capacity or will instead send more waste to commercial facilities. Clearly, the future market for ocean incineration will be influenced to a large degree by such decisions.

Several studies have estimated potential shifts in onsite versus offsite treatment and disposal. CBO (21) projected that the quantity of all hazardous waste sent offsite will roughly double from 1983 to 1990. The magnitude of this shift depends on whether the 1984 RCRA restrictions on land disposal are implemented according to schedule; if delays occur, the increase in offsite treatment would be more gradual. CBO indicated that the trend toward offsite treatment would be particularly strong for wastes that can be incinerated or chemically treated, and that existing capacity in these technologies could be surpassed easily.

A considerably less dramatic shift is forecast by the majority of respondents to an EPA survey of selected commercial hazardous waste management firms (8). According to these respondents, changes in the level of offsite treatment and disposal would be limited at most to a "small (perhaps 4 to 6 percent), short-term pulse," primarily because of facility closures under new RCRA restrictions.[20] Furthermore, they expect that offsite shipment of wastes will eventually decline as waste reduction practices are implemented. A minority of respondents to the survey, however, predicted a larger increase of 10 percent or more in response to RCRA restrictions and also argued that "generators have already exhausted most of their options to reduce waste volumes."

Capacity of and Demand for Offsite Treatment Facilities

The shifting of waste from onsite to offsite treatment is only one of several factors that contribute to the *overall* demand for commercial treatment facilities. Other factors include:

- an increase in actual waste generation, because of economic growth;
- changes that result from new regulatory controls, such as more stringent regulations that govern the burning of hazardous waste in boilers, restrictions on the use of land disposal practices, or increased implementation and enforcement of effluent guidelines;
- closure of existing facilities that are unable to comply with new regulations or unwilling to incur the additional costs of compliance; and
- cleanup of uncontrolled hazardous waste disposal sites.

Several countervailing factors also may affect overall demand:

- an increase in the capacity of existing facilities, whether they are private or commercial;

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[20] Some observers have questioned the reliability of information obtained from existing commercial hazardous waste firms, arguing that these firms have a strong self-interest in downplaying any future need for additional facilities. Aside from this issue, whether such a survey is representative of the industry is questionable; indeed, EPA cautions readers that "no statements can be made about the *entire* commercial hazardous waste management industry from this small sample" (8).

- increasing waste or volume reduction by generators that are seeking to minimize the amounts of waste requiring offsite treatment, and
- increasing use of mobile treatment facilities that are designed to treat wastes at the site of generation.

Each of these factors is very difficult or impossible to assess in any quantitative manner. Nevertheless, several States attempted to account for these factors in studies of future demand for offsite treatment capacity.[21] Virtually all of these studies projected a substantial growth in the demand for offsite capacity into the foreseeable future, although estimates of the magnitude of growth varied considerably.

The studies also support the corollary that a shortfall between offsite treatment capacity and demand is expected if substantial growth in existing capacity does not occur.[22] Given this, capacity could be increased by: 1) developing new facilities, or 2) expanding capacity at existing facilities. Although both of these avenues are being pursued, progress has been very slow:

- The firms surveyed in the EPA study (8) have generally abandoned plans to develop *new* facilities, because of local public opposition and because operating permits cannot be obtained without a minimum delay of several years.
- Some of these firms indicated plans to expand their incineration and other treatment capacity at *existing* facilities; however, they again cited significant delays in obtaining permits as a major obstacle, and argued that "stretching out existing capacity can only go so far. Eventually, new sites must be brought on-line."
- CBO (21) indicated that—at the current rate of permitting for hazardous waste treatment, storage, and disposal facilities—8 to 10 years would be needed to issue the final permits that these facilities must have to continue operating.[23]
- In a survey of private (onsite) treatment facilities in New Jersey, facility owners expressed very little interest in expanding capacity and/or commercializing their operations to help meet the projected shortfall in treatment capacity (5).

This discussion illustrates that the magnitude of the expected shortfall in offsite hazardous waste treatment capacity is exceedingly difficult, if not impossible, to estimate. Despite this, the demand for such capacity clearly will increase. The next section addresses these same issues with a focus on projecting the use of and demand for *incineration* capacity.

Future Use of and Demand for Incineration Capacity

Numerous studies have indicated that the actual use of and demand for *incineration* technologies to manage hazardous waste will increase significantly (1,5,8,16,17,21,28). This trend is a reflection of the ability of these technologies to destroy the organic portion of wastes and significantly reduce waste volume:

> Thermal destruction systems have become recognized over the past decade as an increasingly desirable alternative to the more traditional methods of disposing of hazardous wastes in landfills, lagoons, and injection wells (17).

As one example of these studies, CBO (21) projected that incineration of hazardous wastes would triple or quadruple (from 2.7 mmt in 1983 to 8.2 to 11.6 mmt in 1990). The higher estimate assumed that no waste recycling and recovery beyond current levels would be undertaken; the lower estimate assumed that waste recycling and recovery efforts would achieve the level reflected in tables 6 and 7. CBO also indicated that the increased use of incineration would be the single largest change in the use of all hazardous waste management technologies, and that incineration would increasingly be used to manage organic liquid, sludge, and solid wastes.

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[21] These include efforts undertaken in Missouri, New Jersey (5), New York, North Carolina, and Pennsylvania. References and more detailed analyses of these studies are presented in ref. 24.

[22] For example, the Minnesota Waste Management Board (11) concluded that "there is not sufficient capacity at the present time to treat all of the hazardous wastes amenable to treatment in the United States. As increasing emphasis is put on treatment as an alternative to disposal of hazardous wastes, there may be an overall shortage in treatment capacity." Another observer indicated that "little growth of available commercial incineration capacity may be expected over the short term. A three- to five-year delay is possible before significant new capacity could be available" (17).

[23] Section 213 of the 1984 RCRA Amendments requires that all incineration facilities receive final permits within 5 years of enactment, and all other treatment facilities within 8 years.

The EPA survey of commercial hazardous waste management firms (8) also revealed that increased quantities of waste were being directed toward incineration, a phenomenon clearly attributed by the respondents to the first effects of the new RCRA restrictions on land disposal. At least for the portion of the commercial market represented by this survey, waste quantities received for incineration were increasing at a faster rate than incineration capacity.[24]

The survey respondents argued that future increases in demand for incineration capacity would be primarily for organic solids and sludges, and that liquid capacity was sufficient and would probably remain so. Unfortunately, no data were presented that indicated the relative quantities of the different physical forms of incinerable waste that were received.[25]

Attempts To Project the Future Market for Ocean Incineration

As part of EPA's "Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Waste," Booz-Allen & Hamilton, Inc., conducted an analysis of the near-future *commercial market* for incinerable liquid wastes. The study (26) was intended to directly quantify the potential size of the ocean incineration market. The analysis, however, was complicated by a set of constraints beyond those confronting the studies cited above. Because the study focused on the *commercial* sector of the incineration industry, assumptions had to be made regarding, for example, the relative proportion of incinerable wastes to be managed onsite versus offsite, and the contribution of commercial land-based incineration and other facilities to the overall market picture for incinerable liquid wastes.

The result was a study that has been criticized as being statistically unreliable and as failing to account sufficiently for the use of technologies other than incineration. EPA indicated that the study did not (and was not intended to) fulfill the requirement for EPA to conduct a formal needs assessment for ocean incineration, as specified under the Marine Protection, Research, and Sanctuaries Act. Rather, the study was intended to serve as a general indicator of the size of the potential shortfall in commercial liquid incineration capacity, in support of EPA's contention that there may be a need for ocean incineration. (For a fuller discussion of uncertainties inherent in the market study, see refs. 4,15,26,29).

Despite its flaws, EPA's incineration market assessment was generally consistent with virtually all other available studies. The major finding predicted a significant and growing shortfall in incineration capacity as a result of: 1) increases in the quantities of wastes generated and available for incineration, and 2) very slow development of capacity in incineration and other technologies for managing such wastes.

EPA's market analysis (26) projected the potential demand for ocean incineration based on a quantification of the shortfall in future commercial incineration capacity for *liquid* wastes.[26] A range of projections was derived under scenarios involving implementation of one or more of the land disposal restrictions embodied in the 1984 RCRA Amendments. Assuming full implementation of all of the RCRA restrictions, a range was estimated for the quantity of excess liquid waste that would be shifted away from land disposal. Managing the quantity of wastes at the midpoint of that range would require 33 incinerator ships with a capacity of 50,000 mt per ship per year (or 82 additional land-based incinerators at 20,000 mt per year).

This midpoint projection would represent an increased demand for *commercial liquid waste incineration capacity* of 1.65 mmt annually.[27] As would be expected, CBO's estimate of the increase in *total use of incineration* (i.e., both commercial and private facilities burning liquids, sludges, and solids) was higher, by a factor of 3 to 5.[28] Thus, despite major differences in methodology and somewhat different estimates, these two studies were roughly consistent; both supported the conclusion that, in the near future, there will be increased demand for capacity to manage liquid incinerable wastes.

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[24] These firms reported that the amount of wastes received for incineration increased by 48 percent from 1983 to 1984, while their incineration capacity increased by only 18 percent.

[25] As discussed previously, incinerable liquids are often in demand because of their fuel value. Receiving these wastes from generators is clearly attractive to commercial incineration firms, because burning them reduces the need to use auxiliary fuel when burning solids and sludges that have a lower energy content. Thus, separate discussions of liquid capacity and solids and sludge capacity do not appear to be particularly meaningful.

[26] This finding has been contested by land-based incineration companies (see ch. 2).

[27] The range in projected increased demand was considerable, from 0.75 to 2.55 mmt annually. This corresponded to a range of 15 to 51 incinerator vessels, or 38 to 128 land-based incinerators. The extent of this range is one indicator of the degree of uncertainty accompanying such projections.

EPA's market analysis cast its results in terms of a specific demand for liquid incineration capacity. A more neutral statement of the result, however, is that the capacity to *manage incinerable wastes* is expected to fall short of demand. This shortfall could (and likely will) be addressed in a number of ways. For example, development of ocean incineration capacity *or* expansion of land-based incineration capacity *or* both could help to meet this demand. Alternatively, it could be partially met by other means now used for a portion of these wastes—including chemical treatment, recycling and recovery, and use as fuel in industrial boilers and furnaces. Finally, the quantities of waste requiring treatment could be decreased through increased application of waste reduction practices. Accurately estimating the future use of *any* of these technologies is highly complex, if not impossible.

Thus, a future need for ocean incineration (or land-based incineration, or any other hazardous waste management technology) may never be unequivocally demonstrated or quantified from an *analytical* standpoint. Nevertheless, given the generally acknowledged shortfall in our present and future capacity to manage incinerable wastes, the development of several options will likely be necessary.

Other Factors Affecting Future Waste Generation and Management

The two most important variables with respect to hazardous waste generation and management in the near future appear to be: 1) the extent and schedule of implementation of the new (1984) RCRA authority (which bans certain wastes from land disposal) as well as future changes in the RCRA definition and classification of hazardous wastes (e.g., for waste oils); and 2) the extent of application of new and emerging waste reduction, reuse, and recovery technologies and strategies.

In addition to banning some wastes from land disposal, two other changes in RCRA resulting from the 1984 amendments will increase the quantities of hazardous waste by bringing heretofore unregulated wastestreams or generators under RCRA authority:

1. Exemptions for hazardous wastes or used oils burned as fuel are being removed, and new regulations governing their blending, burning, and recycling for reuse are mandated. CBO (21) estimated that, in 1983, significantly more hazardous waste was burned in RCRA-exempt industrial boilers and furnaces than was incinerated (9.5 mmt versus 2.7 mmt). EPA estimated that 3.4 to 5.4 mmt of hazardous waste and used oils are burned annually in industrial boilers (50 FR 1684, Jan. 11, 1985). See chapter 4 for a detailed discussion of this topic.
2. The waste level below which generators are exempted from regulation has been reduced from 1,000 to 100 kilograms per month, thereby greatly increasing the number of regulated small generators; EPA (50 FR 31285, Aug. 1, 1985) estimated that the number of RCRA-regulated generators would increase from the current 14,000 to a total of 175,000, but that these small generators account for only about 760,000 metric tons per year of hazardous waste (much less than 1 percent of the national total).

Conversely, new RCRA requirements for implementing waste reduction and detoxification programs and increasing industrial efforts aimed toward waste reduction, recycling, and recovery would be likely to moderate or reduce future hazardous waste generation. The full impact of such measures depends on a variety of regulatory, institutional, and economic variables and is therefore exceedingly difficult to predict.

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[28] CBO's range was 8.2 to 11.6 mmt annually. After accounting for current use of incineration at 2.7 mmt annually, this would represent an increase of 5.5 to 8.9 mmt annually. Thus, compared to the EPA value of 1.65 mmt, CBO's values were three to five times higher.

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Chapter 4

Current and Emerging Management and Disposal Technologies for Incinerable Hazardous Wastes

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Chapter 4

Current and Emerging Management and Disposal Technologies for Incinerable Hazardous Wastes

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Incinerable wastes are currently managed by a broad array of methods; how extensively each method is used depends on innumerable economic, regulatory, and geographic factors. In addition, a wide range of new technologies for managing hazardous wastes is being developed, and many apply directly to incinerable wastes. This chapter first summarizes available data on the quantities of incinerable waste currently managed by particular methods and examines each method in more detail with respect to its potential for influencing the use of ocean incineration. Then the chapter briefly describes several new technologies with respect to their availability, capacity, and degree of applicability to incinerable wastes.

The discussion specifically excludes the large quantities of hazardous waste present in wastewaters that are directly and indirectly discharged into surface waters. Such disposal practices are regulated under the Clean Water Act and are specifically exempted from Resource Conservation and Recovery Act (RCRA) regulations applicable to hazardous waste. Moreover, only a small portion of incinerable liquid wastes is discharged into surface waters. Another OTA report (21) will examine these practices in detail.

INCINERABLE WASTE QUANTITIES CURRENTLY MANAGED BY VARIOUS TREATMENT AND DISPOSAL METHODS

Several studies have estimated the quantities of hazardous waste managed through treatment, disposal, and recycling or recovery (6,18,24). However, only one study—by the Congressional Budget Office—was aggregated by waste type; this allowed separate estimates to be developed for the various categories of *incinerable* hazardous waste, which include waste oils, halogenated and nonhalogenated solvents, and other organic liquids (ref. 18, and unpublished data).

The CBO estimates for the overall disposition of hazardous waste differed significantly in some cases from those of the Environmental Protection Agency (24).[1] The sources of data for both studies contain uncertainties and systematic errors which likely contribute to such differences. In addition, the universe of hazardous wastes considered in the two studies differs significantly: CBO adopted a definition that is much broader than the RCRA definition used by EPA. Finally, CBO assumed full compliance with RCRA and Clean Water Act requirements in generating its estimates. Given these sources of uncertainty, the following discussion will provide a range of estimates, wherever possible, to provide a qualitative picture of current management of hazardous waste that could be incinerated.

Available data indicate that large quantities of waste that could be incinerated are currently being disposed of on land—in landfills, surface impoundments, or injection wells. Of liquids that could be incinerated at sea, CBO estimates that almost a third of oils and solvents and more than 80 percent of other organic liquids are disposed of on land. For incinerable sludges and solids, reliance on land disposal is even higher: CBO estimates that more than 80 percent of these wastes are land-disposed.

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[1] CBO acknowledged this discrepancy and discussed differences in the methodologies of the two studies in a paper (19) which accompanied its 1985 report (18).

The CBO data also indicate that most waste oils (about 60 percent) and significant quantities of waste solvents (5 to 10 percent) are burned in RCRA-exempt industrial boilers, currently under little or no regulation. These data are generally consistent with those from other sources (refs. 4 and 13; 50 FR 1684, Jan. 11, 1985).

The 1984 RCRA Amendments were designed to significantly restrict the use of these options for managing hazardous wastes, because of concerns about adverse impacts to human health and the environment. If the restrictions are implemented according to schedule, they are likely to significantly increase the quantities of waste available for or directed to incineration.

CBO's data and other data indicate that significant quantities of incinerable wastes, particularly liquids, are currently being recovered, reused, or recycled. These practices are likely to be increasingly used in the future. As shown in table 6 (see ch. 3), however, despite the anticipated levels of recovery, reuse, and recyling, it is likely that most incinerable hazardous wastes generated by 1990 will continue to require some form of treatment or disposal.

CURRENT USE OF PARTICULAR TECHNOLOGIES FOR MANAGING INCINERABLE WASTES

Hazardous waste management technologies can be organized into a generally accepted hierarchy of methods ranging from least to most environmentally desirable or sound. This hierarchy can best be represented by a hazardous waste management "pyramid," with the following tiers:

- dispersion in the environment;
- isolation or containment;
- stabilization of waste through physical or chemical means;
- destruction or treatment of wastes to reduce toxicity;
- recovery of waste for recycling or reuse of materials or energy; and
- reduced generation of waste, with respect to both volume and toxicity.

A particular technology may actually contain elements from more than one tier in the hierarchy. For example, ocean incineration entails destruction of most of the waste, dispersion of a small amount of unburned wastes into the environment, and containment of any residuals by disposing of them in landfills. This section briefly discusses technologies (other than incineration) in light of the above hierarchy and indicates which technologies contain elements of more than one tier. Currently available incineration technologies are discussed in chapter 5.

Land Disposal

Large quantities of incinerable hazardous wastes are now disposed of on land. Land disposal includes three primary methods: underground injection, landfilling, and surface impoundment. Although they are meant to isolate and contain wastes, all three methods have often resulted in dispersion of wastes, through leakage and migration of wastes from the disposal site. In some cases, wastes are stabilized prior to disposal in order to lessen the risk or degree of dispersion.

If implemented according to schedule and congressional intent, the 1984 RCRA Amendments' restrictions on land disposal would shift large quantities of hazardous waste, particularly incinerable liquids, away from land disposal. Almost all of the RCRA prohibitions, however, are contingent on the availability of alternative capacity for managing banned wastes. If alternatives are unavailable, temporary variances can be granted.

Underground Injection

The injection of hazardous wastes into deep wells is the disposal technology used most often for such wastes. In 1983, an estimated 44 million metric tons (mmt) to 67 mmt, or one-sixth to one-quarter of

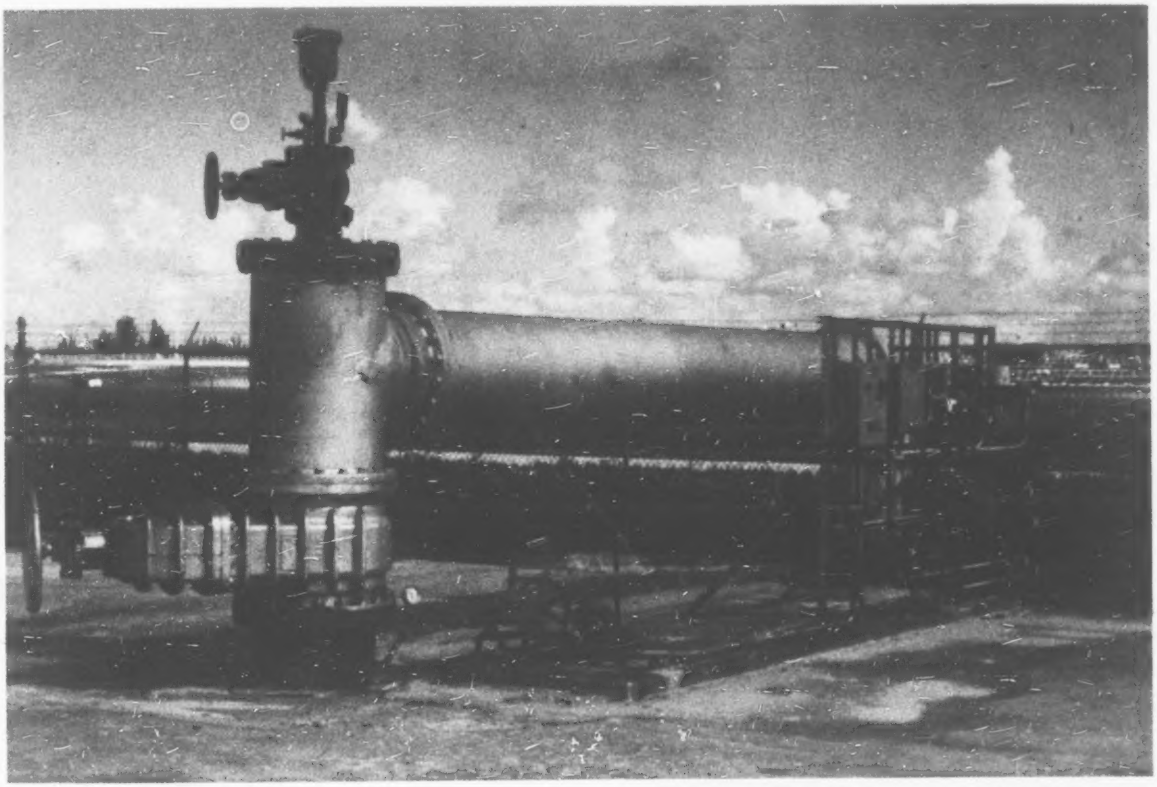

Photo credit: State of Florida Department of Environmental Regulation

Underground injection into deep wells is the technology most used to dispose of hazardous wastes.

all hazardous wastes generated, were disposed of by underground injection (ref. 18; EPA, cited in ref. 19). The 1984 RCRA amendments impose new requirements on this practice, although they are less stringent than those applicable to landfilling and surface impoundment. The schedule for banning the underground injection of hazardous waste is more gradual and the burden of proof of adverse impact may be somewhat more stringent.

Landfilling

CBO (18) estimated that over one-fifth of all hazardous wastes generated in 1983 was disposed of in landfills. Increasingly stringent RCRA requirements are raising costs, however, and are expected to lead to decreased usage. Minimum technology standards embodied in the 1984 RCRA Amendments require the use of double liners, leachate collection systems, and groundwater monitoring capability. Landfilling of bulk liquid hazardous waste is already prohibited, and prohibitions on landfilling of other hazardous wastes are being decided on a legislatively mandated schedule.

Surface Impoundment

Surface impoundments, which include ponds, pits, and lagoons, are used to store and treat, as well as dispose of, many hazardous wastes. CBO (18) estimated that almost one-fifth (50 mmt) of all hazardous wastes generated in 1983 was placed in surface impoundments. Treatment processes used in surface impoundments include volatilization, evaporation, aerobic or anaerobic digestion, and coagulation and precipitation. Under the 1984 RCRA Amendments, the same minimum technology standards applicable to landfills now apply to surface impoundments, although the immediate ban on bulk liquid hazardous waste does not apply.

Use of Incinerable Waste as Fuel

A variety of technologies use incinerable waste as a fuel source. These technologies embody elements of the treatment/destruction and recovery tiers in the waste management hierarchy. In addition, disposal of residuals from such processes may involve isolation/containment or dispersion of wastes, as well.

Technologies employing incinerable waste as fuel compete directly with both land-based and ocean incineration. A regulatory distinction exists, however, between thermal technologies whose primary purpose is to use and capture the energy content of raw fuel or hazardous waste, and typical incineration technologies, which are designed primarily for the purpose of destroying wastes (46 FR 7666, Jan. 23, 1981).[2]

Various types of boilers and furnaces, both industrial and nonindustrial, employ incinerable waste as fuel to some extent. Nonindustrial boilers are used largely for space heating in apartments, office buildings, schools, and hospitals. Industrial boilers are used for space heating and steam production by utilities or other industrial facilities.

Industrial furnaces include cement and lime kilns, asphalt plants, and steel blast furnaces. Some of these technologies use the chlorine as well as the energy from hazardous wastes. For example, cement kilns use the acid gas formed from burning chlorinated wastes to reduce the alkalinity of the cement slag; the kiln itself acts essentially as a scrubber, and the quality of the cement product is actually improved in the process.

Profile of Existing Facilities Using Incinerable Waste as Fuel

This section provides a profile of the number of these facilities and the extent of their use in burning hazardous wastes as fuel.

A very large number of industrial boilers and furnaces are used in the United States. EPA estimates that about 43,000 industrial boilers and 600 industrial furnaces are currently in operation (4,13). Of these, about 1,300 boilers and 10 to 20 furnaces burned some waste oil or hazardous waste-derived fuel in 1983 (25). EPA estimated that 3.4 to 5.4 mmt of hazardous waste and used oils are burned annually in industrial boilers (50 FR 1684, Jan. 11, 1985) and that about 0.35 mmt are burned annually in industrial furnaces (24). CBO (18) reported a much higher estimate of 9.5 mmt for industrial boilers *and* furnaces. In any case, significantly more hazardous waste is burned in industrial boilers and furnaces than is incinerated: 1.7 to 2.7 mmt (18,24).

While industrial furnaces and boilers appear to have enormous capacity for hazardous wastes, several factors limit their use. First, although these practices were exempted from RCRA regulations, the 1984 RCRA Amendments call for their regulation as hazardous waste facilities (see below). Second, these facilities have tended to burn only hazardous wastes that are relatively clean and have a high energy content. Attempts to significantly expand their use would involve wastes that are less attractive to facility operators, because they contain higher amounts of ash, water, or solids (13). Indeed, the reluctance of many operators to use such wastes for fuel is reflected in the small proportion of existing facilities that actually burn hazardous wastes (as indicated above).

A third factor limiting the use of these facilities for hazardous wastes is the relative lack of rigorous environmental testing or appropriate pollution control equipment. Very few industrial boilers are equipped with scrubbers (12,13), so that wastes with significant chlorine or ash content could not be burned; moreover, the corrosivity of the resulting exhaust gases would damage the boilers.

A fourth factor limiting such use is the chlorine content of wastes. Wastes of intermediate chlorine content can be burned in cement kilns and other industrial furnaces, where corrosive gases are directly used in the production process. Burning of chlorinated wastes in kilns, however, tends to increase the release of particulates, necessitating that facilities be upgraded prior to such use (12). These and other factors limit the chlorine content of wastes that can be burned in such facilities.

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[2] Incineration technologies are discussed in ch. 5.

In some States, industrial furnaces have experienced regulatory problems when burning hazardous wastes and have been forced to stop accepting certain or all such wastes. This has led to increasing quantities of waste being sent to commercial incinerators (2).

Regulation

Some regulation of hazardous waste burning in boilers and furnaces has already occurred, and more is likely in the near future. Burning of hazardous waste in nonindustrial (particularly residential) devices is now strictly regulated and for the most part prohibited (50 FR 49164, Nov. 29, 1985). The 1984 RCRA Amendments prohibit burning of hazardous waste in cement kilns located in cities with populations exceeding 500,000 unless the facility complies with RCRA incineration standards (Section 204(b)(2)(c)).

For facilities producing fuels containing hazardous waste, notification and labeling requirements and product standards were also mandated and are currently being developed. In addition, exemptions for hazardous wastes or used oils burned as fuel are being removed, and new regulations governing their blending and burning are mandated. Finally, in 1986 EPA expects to issue permit standards that would extend the current performance standards and requirements applicable to land-based incinerators to all industrial boilers and furnaces (50 FR 49164, Nov. 29, 1985).

Biological and Physical/Chemical Treatment[3]

Many technologies for treating hazardous wastes are applicable to incinerable wastes. Biological methods include traditional aerobic and anaerobic digestion, in which naturally occurring bacteria are used to metabolize the organic constituents of the waste. Aerobic processes generally can be used only with relatively dilute wastestreams (liquids that contain low levels of solids), because high concentrations of waste components or metabolic products are often toxic to bacteria. Anaerobic procedures are less sensitive, and have been used to digest sludges that contain significant amounts of solids.

Biologists have isolated naturally occurring bacteria that can degrade particular toxic or persistent chemical compounds (5,23). Particularly for specialized and highly problematic wastes such as PCBs, these and other emerging biological approaches may prove extremely useful and cost-effective.

Traditional physical/chemical treatment entails removing organic or metallic compounds from aqueous wastes—by using coagulants, adsorbents such as activated carbon, or chemical reactions—and then destroying or disposing of the contaminated residues. Newer methods applicable to incinerable waste include several related technologies for dechlorination. Such processes chemically strip off chlorine atoms from highly chlorinated organic compounds, thereby greatly decreasing or eliminating their toxicity and persistence. Mobile units have been developed specifically to detoxify PCB-contaminated transformer fluids and PCB- or dioxin-contaminated soils.

Waste Recovery and Recycling

Current methods for recovering waste have been applied primarily to waste solvents and oils. **Solvent recovery** is a well established industry, which handles most of the waste solvents that are generated (18). Solvents are often sent offsite to be purified and returned to the generator for a fee. In other cases, the recoverer resells solvents to new customers.

Solvent recovery consists of several independent processes, which result in sequentially cleaner material. Some loss of quality relative to virgin materials accompanies all of these processes. Although this can lower the demand for recovered solvents, markets currently exist for both partially and fully recovered solvents. The intended use determines the extent of treatment; for example, use as fuel requires only minimal treatment, whereas reuse as solvent may require substantial treatment and expense.

The initial step in solvent recovery usually is to remove suspended impurities by filtration and centrifugation. Separation and removal of water, or separation of different solvents present in a mixture, is accomplished through various forms of distillation. Each of these processes generates a residual, which must be disposed of or destroyed. For example, distillation generates various still wastes, which are candidates for incineration (on land or at sea).

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[3] Although incineration and other thermal processes are often classified as treatment technologies, this discussion is limited to nonthermal processes.

Waste oil recovery, which is used to a much smaller extent than is solvent recovery, also entails several processes that produce sequentially cleaner material. Specifications based on intended reuse have been established, and they largely dictate the extent and nature of treatment. Reclaiming waste oil entails removing suspended solids, water, and degraded oil compounds. Reclaimed oils are blended or reformulated, resulting in products that can be resold for uses that do not require oil meeting the specifications for virgin material. Refining of reclaimed oil is accomplished through fractional distillation to generate a final product that approaches original specifications.

In addition to the new RCRA requirements that apply to the blending and burning of fuels containing hazardous waste, EPA has proposed listing used oil as a hazardous waste under RCRA (50 FR 49258, Nov. 29, 1985) and has proposed regulations governing recycled oil (50 FR 49212, Nov. 29, 1985). The regulations would ban the use of recycled oil for oiling roads and would extend to recycled oil those regulations that govern other recycled hazardous wastes.

A third method of waste recovery applicable to many types of waste is **liquid extraction**. This technique is especially useful for recovering a dissolved waste component that has economic value in its pure form. For example, phenol can be recovered in this manner from refinery and coke oven wastes.

A number of newer technologies, which have not been widely employed in the United States, can directly recover or use the chlorine released when chlorinated wastes are thermally destroyed. These processes are discussed in the section on new and emerging technologies.

Waste Reduction

Although the term waste reduction has a very broad meaning in common usage, in its most precise connotation it refers to technologies and processes that reduce the actual generation of waste (measured in terms of volume, or in terms of the toxicity or degree of hazard per unit volume). A technology like incineration reduces the toxicity and volume of waste, but a true waste reduction technology or process is used *before* the wastes are actually generated (i.e., in order to prevent their generation). The term, therefore, also excludes waste recovery technologies that reduce the quantity of waste requiring treatment or disposal but that act after the waste is generated.

Waste reduction technologies generally fall into two categories. First, **process modifications** reduce waste generation by, for example, internal recycling or more efficient use of feedstocks. These measures are typically process-specific, and the modifications are often driven by direct economic incentive. Even modifications that are not tied to the process itself have often been used to reduce waste (e.g., computer-based scheduling and inventory control in paint manufacturing) (1).

A second category of waste reduction technologies includes **product or ingredient substitution**, in which toxic or polluting materials are replaced by safer components. For example, water-based inks or adhesives can sometimes be substituted for those containing or made with organic solvents.

A full discussion of waste reduction far exceeds the scope of this study. For additional information, see references 3,9,14,15,16.[4]

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[4] Another ongoing OTA assessment (20) examines in detail the potential for industrial waste reduction.

NEW AND EMERGING TECHNOLOGIES FOR INCINERABLE WASTES

A wide range of new technologies is being developed for the management of hazardous wastes. Many of these technologies, including methods for the recovery as well as detoxification (through treatment or destruction) of wastes, apply directly to incinerable wastes. A full analysis of the new technologies would exceed the scope of this assessment, but the topic has been examined in detail by others (7,8,11,22). This section briefly describes a few promising technologies and, where data are available, discusses their status, capacity, and degree of applicability to incinerable wastes.

Recovery Processes

Solvent Recovery—Thin Film Evaporation

This technology, in which waste solvent is fractionated by evaporation from a thin film applied to a heated surface, provides an alternative to conventional solvent distillation. The technology's primary advantages over conventional distillation are a higher efficiency of recovery (greater than 95 percent), a smaller amount of residual material requiring disposal or destruction, and the ability to recover even highly viscous liquids.

A few commercial solvent recovery firms have recently installed thin film evaporators (1), but data on current or near-future capacity are not available.

Advanced Oil Recovery Processes

Application of advanced petroleum technology to waste oil has resulted in a number of new methods for removing contaminants and fractionating oil, thereby producing material that closely approximates original specifications. Several of these methods have recently been put into operation. The extent to which they would be applied to incinerable wastes would partly depend on oil prices and the relative cost of existing alternatives, including incineration.

Chlorine Recovery Processes

Several emerging technologies can use the chlorine that is released during the incineration of highly chlorinated organic wastes (17). These technologies fall into two major classes. First, certain processes can recover chlorine liberated during incineration in the form of concentrated hydrochloric acid. These processes are generally applicable to a broad range of chlorinated organic wastes, but they have only been used on a small scale to date, probably in part because they are not competitive with other industrial sources of hydrochloric acid (10). Second, a group of related chlorination processes directly use liberated chlorine in additional chemical chlorination reactions. These technologies can be applied, for example, to the production of chlorinated hydrocarbons such as trichloroethylene, but the waste used in the process must be quite pure and homogeneous. To date, only wastes generated in the production of vinyl chloride and propylene oxide have been used successfully in chlorination recovery processes.

Both types of processes are limited by the market's capacity to absorb their products. In addition, the technologies have been used primarily in Europe and have not found significant application in the United States. Current costs are several times higher than those for ocean incineration of the same wastes, although the return on recovered materials can sometimes alter the ratio. From an environmental perspective, these recovery processes offer the advantage of occurring in relatively closed systems, thus greatly reducing the emissions associated with conventional incineration.

Supercritical Fluid Extraction

This process is an advanced form of liquid extraction, employing elevated temperature and pressure to extract particular organic compounds from waste mixtures. The process entails higher capital investment but lower operating costs than conventional distillation or solvent extraction. As with liquid extraction, supercritical fluid extraction is likely to be most useful for treating aqueous wastes containing valuable or highly toxic components. It may also be able to concentrate the organic portions of wastes in order to render their subsequent incineration more economical.

Thermal Detoxification Processes[3]

High-Temperature Electric Reactor

This technology is an advanced pyrolytic technique in which wastes are rapidly heated to extremely high temperatures (about 4,000° F) and destroyed. Its developer claims that the destruction efficiencies the reactor achieves are much higher than those required of, or achieved by, conventional incinerators. The reactor was initially developed to destroy organic contaminants in soils or carbon adsorbents, but it has recently been used for liquid wastes, as well.

The reactor's throughput for solids is estimated to be as high or higher than that of conventional incineration, although for liquids the converse may be true. Commercialization is underway.

Molten Salt

This technology destroys organic wastes and removes inorganic residuals from combustion gases in a single step. Wastes are injected into a pool or bath of molten sodium carbonate or calcium carbonate maintained at a temperature of about 1,650° F; the inorganic byproducts of combustion (containing phosphorus, sulfur, halogens, or metals) react with the carbonate component of the bath and are retained as inorganic salts. These products, as well as ash, must be periodically removed from the bath.

Molten salt baths are suitable for both liquid and solid wastes (including highly halogenated wastestreams) with low ash content. Throughput of a pilot-scale facility was estimated to be about 100 lbs/hr. No commercial units are currently employed, although they are available for purchase.

Molten Glass

A similar technology employing a molten glass bath maintained at about 2,200° F has also been developed. Inorganic components other than halogens are trapped and removed in a glassified, and therefore highly stabilized, form. Scrubbers are necessary when this technology is used with halogenated wastes.

Fluid Wall Reactor

In this process, wastes pass through a porous carbon cylinder heated to about 2,200° F. A mobile unit has been developed for destroying dioxin-contaminated liquids and soils. Projected costs are comparable to those of offsite incineration.

Plasma Arc

Wastes are destroyed in this process by injection into an electrically superheated ionized gas (plasma). Temperatures employed are claimed to be extremely high: 10,000° F or more. An afterburner is usually attached to ensure complete destruction. The method has been used on PCBs and other highly chlorinated liquid wastes, and has demonstrated very high destruction efficiencies (higher than 99.9999 percent). A unit currently being demonstrated has a waste throughput of 600 lbs/hr. A commercial unit is expected to be available within a few years. The costs, which are projected to be 5 to 10 times higher than conventional incineration, would probably limit the technology's use to highly toxic liquids.

Supercritical Water Reactor

In this process, elevated temperature and pressure enhance the rate and efficiency of thermal oxidation of aqueous wastes. Inorganic constituents are either neutralized or precipitated, eliminating the need for scrubbers on systems fed with chlorinated wastes. Destruction efficiencies of demonstration units have been somewhat lower than those required of incinerators.

A reactor system now being developed would treat liquids and sludges containing high levels of inorganic and toxic constituents. The unit would be equipped with heat recovery capability as well. Throughput is expected to be between 1,000 and 2,000 gallons per day (300 to 600 lbs/hr). Commercialization is expected to occur within several years.

Chemical Detoxification Processes

As a general rule, incinerable wastes are not good candidates for chemical treatment. Particular wastes such as PCBs and dioxins, which have been the focus of considerable public attention, may be exceptions to this generalization. For more information about chemical detoxification processes, see ref. 1.

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[3] This discussion is drawn primarily from refs. 1 and 8.

Oxidative Ultraviolet Light Treatment

This process couples the oxidative capacity of ozone or hydrogen peroxide with the ability of high-energy ultraviolet light to break chemical bonds. Several techniques are being developed, but they are likely to be quite expensive, especially for waste with significant organic content, thus limiting their ability to compete with incineration. The techniques may, however, be useful for hard-to-treat wastes such as PCB- and dioxin-containing solids.

Catalytic Dehalogenation[6]

Two dehalogenation processes are being developed. One would be applicable to liquids with low organic halogen content, the other to pure halogenated compounds or liquids with highly concentrated halogenated compounds. The first process would replace halogen (usually chlorine) atoms with hydrogen, detoxifying the original compound or rendering it less stable. The halogen gas generated in the process would have to be treated in a scrubber device. In the second process, the original compound would be oxidized to carbon dioxide and water, and the halogen would take the form of the pure element (e.g., chlorine gas), which could be recovered.

The feasibility of both processes has been established in pilot-scale units, but neither has yet been employed commercially. Both systems are expected to be suitable for use in mobile units, which could be employed at cleanup sites, but would probably be too small for major commercial operations.

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[6] Most halogenated chemicals contain chlorine rather than other halogens; the processes discussed below are, therefore, often referred to by the term *dechlorination*.

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Chapter 5

Current Land-Based Incineration Technologies

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Chapter 5

Current Land-Based Incineration Technologies

A variety of technologies are used to thermally destroy hazardous wastes. In its strictest sense, incineration means the high-temperature destruction of wastes carried out in the presence of oxygen. For practical purposes, however, certain other thermal destruction technologies that destroy wastes using little or no oxygen (i.e., pyrolysis and starved air incineration) can be be grouped with incineration technologies.[1] This section briefly describes the distinctive features of the various processes that thermally destroy hazardous wastes.

All waste incinerators have several common components: a waste feed system, a combustion air or oxygen system, a combustion chamber, combustion monitoring systems, and (where required) an air pollution control and ash removal system. The actual applications of the various components vary somewhat in different designs. The following brief description of available incineration technologies discusses each of these features.

TRADITIONAL INCINERATION TECHNOLOGIES

Liquid Injection Incineration

Liquid injection incineration is, by far, the most common incineration technology used on land (primarily onsite), and is the only technology being used or considered for ocean incineration. As the name implies, liquid injection incineration can accommodate only freely flowing (pumpable) liquid or slurry wastes. When coupled with other types of incinerator designs, this technology serves as a secondary chamber (afterburner) for volatilized constituents produced by the primary incinerator.

Liquid injection incinerators are designed with almost no moving parts and are almost exclusively single-chamber units. (Figure 3 depicts in schematic form a typical liquid injection incinerator.) Wastes are typically injected into the combustion chamber after being atomized (i.e., broken up into very fine droplets) by passage through a nozzle or rotating cup located in or near the burner. A forced air draft system supplies the oxygen required for combustion and also provides turbulence to aid in mixing. The combustion chamber itself is typically a refractory-lined (heat-resistant) cylinder, which can be mounted either vertically or horizontally.

Combustion gases are vented directly to the atmosphere, if they comply with air pollution regulations for incinerators. If halogenated wastes are burned, scrubbers capable of removing acid gases may be required. Incineration of liquids usually results only in very low particulate emissions and, therefore, does not usually require particulate removal equipment.

Rotary Kiln Incineration

Rotary kiln incineration is the technology most commonly used by major commercial land based facilities and is the third most common incinerator design in the United States. Rotary kilns can accommodate a wide range of solid and sludge wastes, including dry flowable granular wastes, containerized wastes, nonpumpable slurries, and semisolids. Rotary kilns are generally equipped with sec-

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[1] The destruction of hazardous wastes in boilers and furnaces (see ch. 4) is a common practice that is only beginning to come under regulation; however, under current regulations (46 FR 7666, Jan. 23, 1981), these practices are distinguished from incineration because wastes are burned in boilers and furnaces for the *primary* purpose of recovering their energy content, not for the purpose of destroying the wastes. EPA estimated that, in 1981, almost twice as much hazardous waste was burned in boilers and furnaces than was burned in incinerators (4).

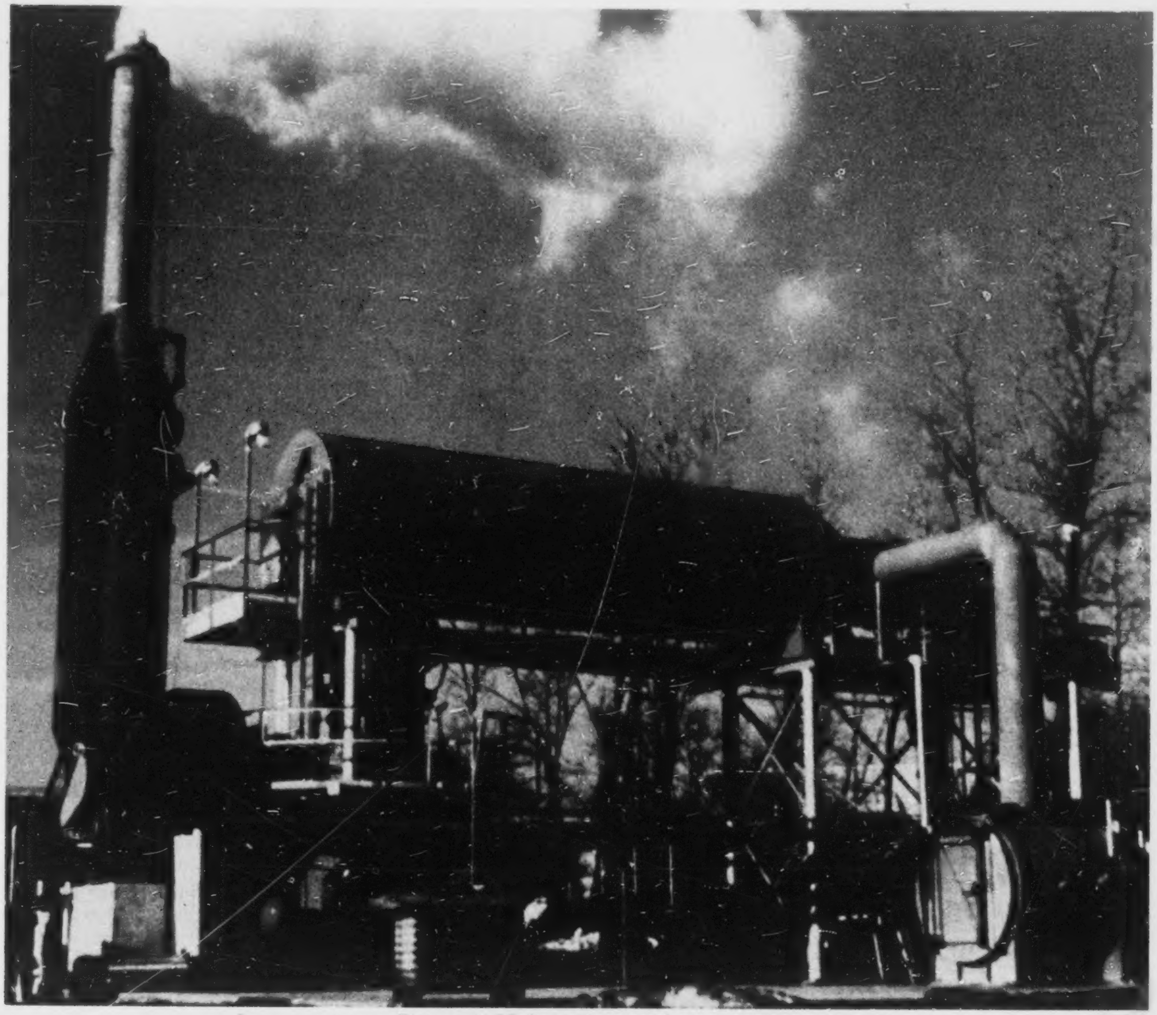


Photo credit: E.T. Oppelt, Hazardous Waste Engineering Laboratory, U.S. Environmental Protection Agency

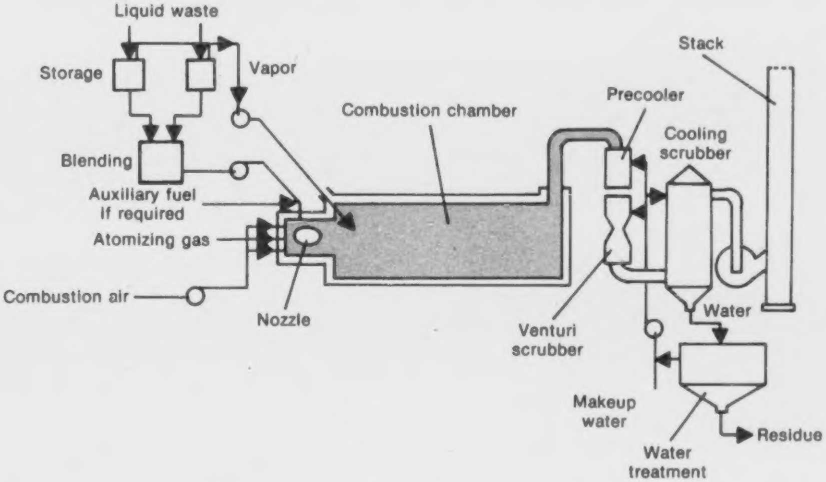
Liquid injection incineration, the most common incineration technology in the United States, is typically used by waste generators to destroy their own liquid wastes onsite. It is the only technology being used or considered at this time for ocean incineration.

ondary combustion chambers (afterburners) to increase the length of time during which wastes are subjected to the high temperatures necessary to ensure complete destruction.

The major commercial facilities operate large rotary kilns, coupled with liquid injection units to accommodate liquid wastes. Rotary kiln technology is not currently applicable to at-sea operation, nor is it likely to be in the foreseeable future, because of design and spatial constraints. The capital costs of rotary kiln technology are significantly higher than those of liquid injection systems.

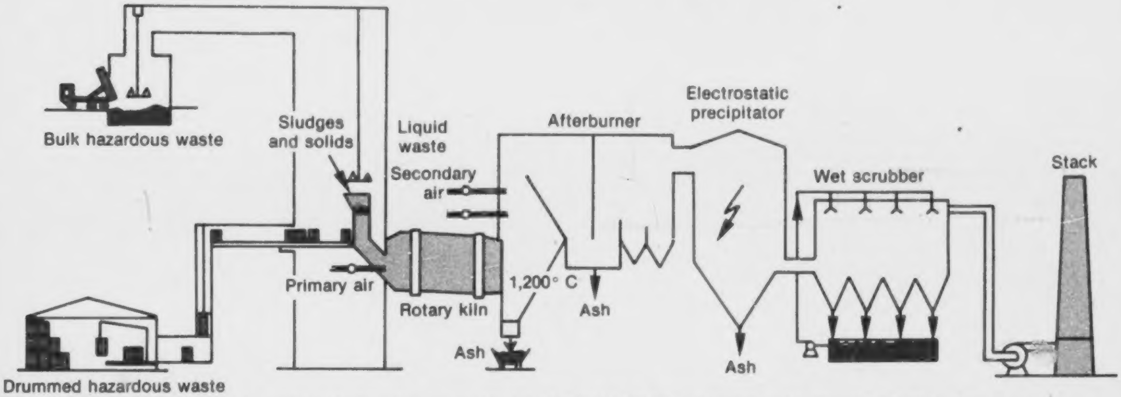
The combustion chamber of a rotary kiln incinerator consists of a slowly rotating, refractory-lined cylinder mounted at a slight incline to aid gravity feed of wastes. (Figure 4 is a schematic representation of a typical rotary kiln incinerator.) Solid and sludge wastes enter at its high end, and liquid wastes or auxiliary fuel are introduced as needed through nozzles. Ash moves to the low end of the

Figure 3.—Liquid Injection Incineration Technology


Liquid waste
Storage
Vapor
Blending
Auxiliary fuel if required
Atomizing gas
Combustion air
Nozzle
Combustion chamber
Precooler
Stack
Cooling scrubber
Venturi scrubber
Water
Makeup water
Water treatment
Residue

SOURCE: Arthur D. Little, Inc., *Overview of Ocean Incineration*, prepared by J.R. Ehrenfeld, D. Shooter, F. Ianazzi, and A. Glazer for the Office of Technology Assessment (Cambridge, MA: May 1986).

Figure 4.—Rotary Kiln Incineration Technology


Bulk hazardous waste
Sludges and solids
Liquid waste
Secondary air
Primary air
Rotary kiln
1,200° C
Ash
Afterburner
Ash
Electrostatic precipitator
Ash
Wet scrubber
Stack
Drummed hazardous waste

SOURCE: Arthur D. Little, Inc., *Overview of Ocean Incineration*, prepared by J.R. Ehrenfeld, D. Shooter, F. Ianazzi, and A. Glazer for the Office of Technology Assessment (Cambridge, MA: May 1986).

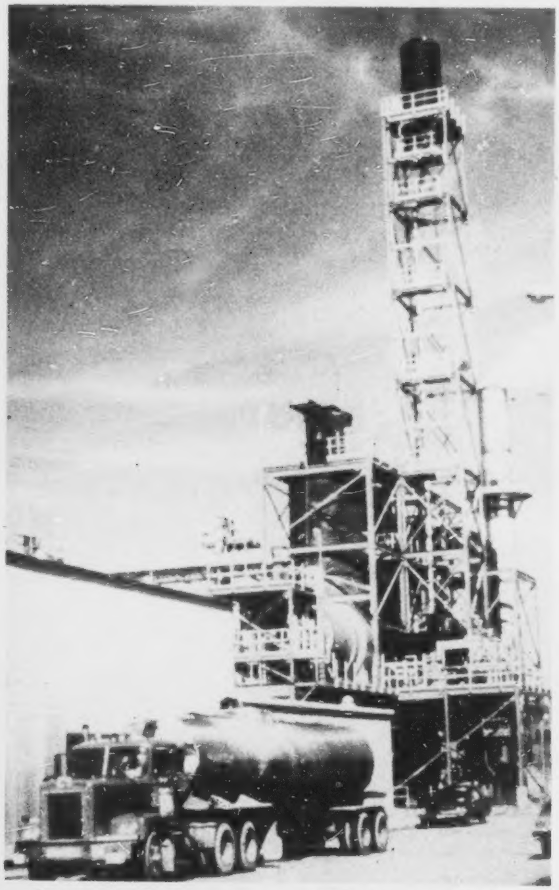


Photo credit: E.T. Oppelt, Hazardous Waste Engineering Laboratory, EPA

Rotary kiln incineration can destroy a wide range of hazardous wastes—solids, sludges, and liquids—and is the technology most frequently used at commercial facilities.

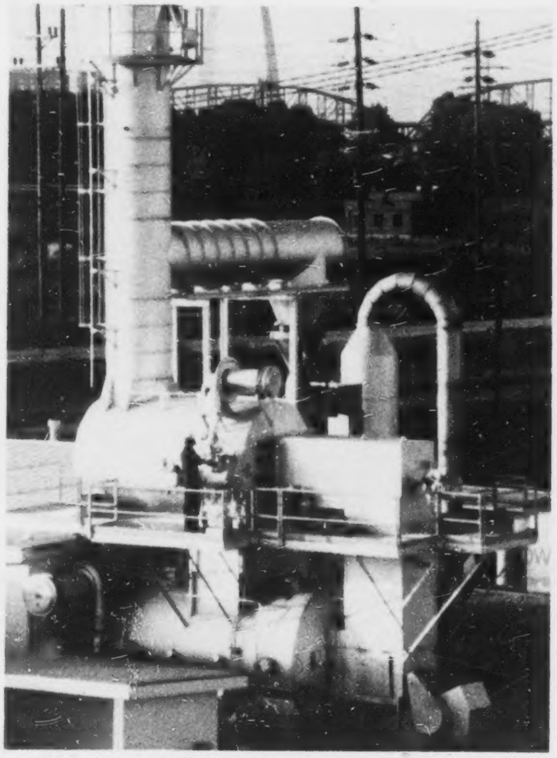


Photo credit: Trade Waste Incineration/Air Pollution Control Association

Fixed hearth incinerators are commonly used to burn solids and sludges at the site of generation. This particular facility has been equipped with liquid injection equipment to allow the incineration of liquid hazardous wastes as well.

kiln, where it can be removed for disposal. After being volatilized and partially destroyed in the primary chamber, gases are directed to the secondary chamber to complete the destruction process.

Incinerating solid wastes creates appreciable ash residues and particulates, so rotary kilns are typically equipped with stack scrubbers to clean flue gases.

Hearth Incineration

Hearth incineration, which is the second most common design in the United States, is employed primarily to burn wastes onsite. Hearth incinerators are designed to burn waste in solid and sludge form, but they can also be equipped with liquid injection capability.

Wastes are introduced onto a platform (hearth) in the bottom of the combustion chamber. Both fixed- and multiple-hearth designs are in use. Multiple-hearth designs, in which wastes are conveyed from chamber to chamber, are especially useful for burning complex wastes that need to be exposed to high temperatures for long periods. Incineration in fixed hearth units can occur under conditions of excess air or starved air (pyrolytic) conditions. Pyrolytic systems are generally accompanied by excess-air afterburners.

Although air flow over the waste mass can be controlled to limit the amount of particulate matter in the exhaust gases, scrubbers are often necessary to comply with air pollution regulations.

Fluidized Bed Incineration

Fluidized bed incineration uses a layer of small particles (e.g., sand) suspended in an upward flowing stream of air. (Figure 5 schematically illustrates a fluidized bed incinerator.) The particles behave much like a fluid (hence, the name). Wastes (and auxiliary fuel, if needed) are mixed into the suspended bed and combusted. Fluidized bed incinerators were developed primarily to accommodate highly viscous liquids and sludges not easily burned in more conventional types of incinerators.

Combustion gases from this type of incineration typically contain high levels of particulates and, therefore, must be scrubbed before release to the atmosphere.

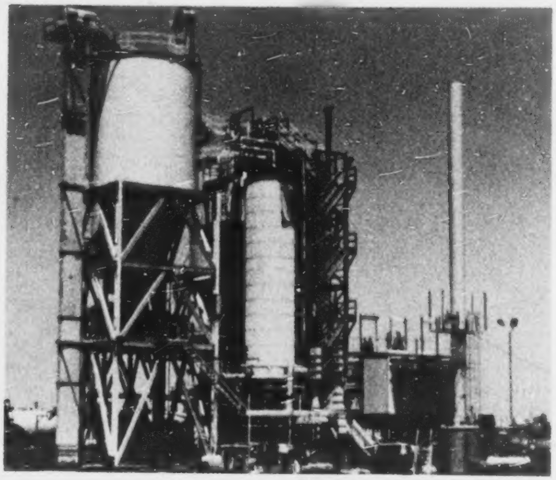
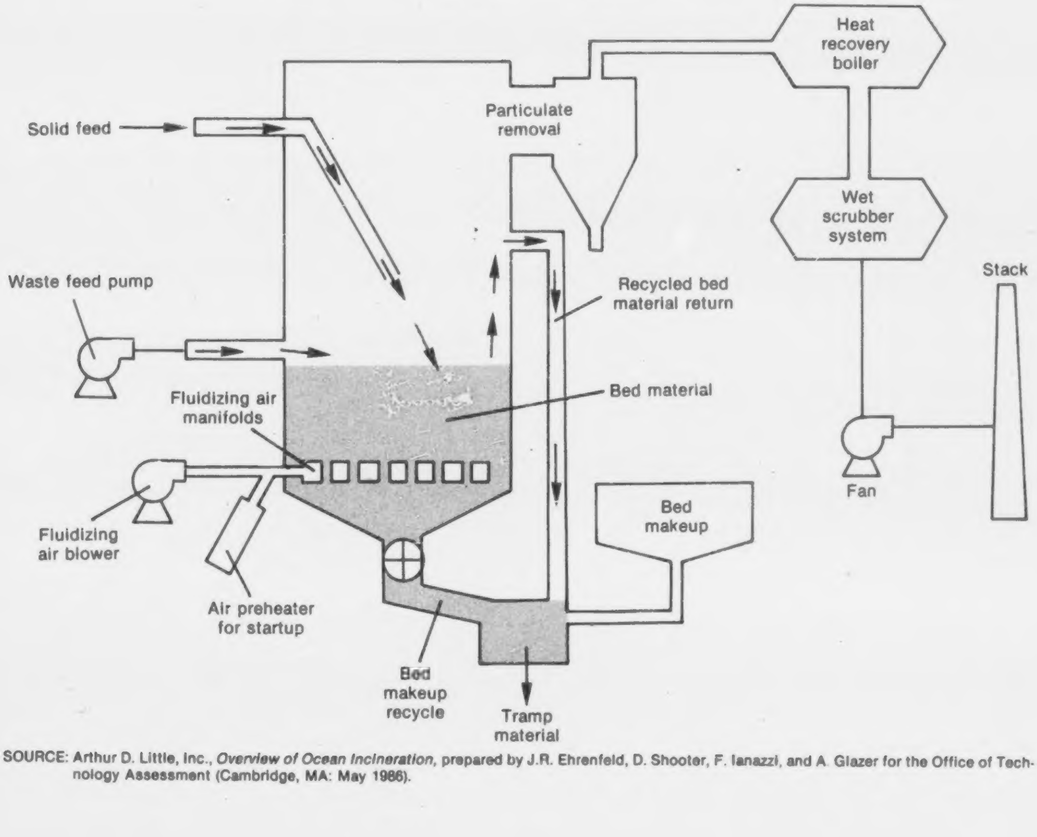


Photo credit: GA Technologies, Inc.

Fluidized bed incinerators can destroy liquids and sludges that are not easily handled by more conventional incinerator technologies.

Figure 5.—Fluidized Bed Incineration Technology


Heat recovery boiler
Solid feed
Particulate removal
Wet scrubber system
Waste feed pump
Recycled bed material return
Stack
Fluidizing air manifolds
Bed material
Fan
Bed makeup
Fluidizing air blower
Air preheater for startup
Bed makeup recycle
Tramp material

SOURCE: Arthur D. Little, Inc., *Overview of Ocean Incineration*, prepared by J.R. Ehrenfeld, D. Shooter, F. Ianazzi, and A. Glazer for the Office of Technology Assessment (Cambridge, MA: May 1986).

Several other incinerator designs are currently in operation. These include fume incinerators (typically with liquid waste incineration capability) for burning gaseous wastes, incinerators for destroying ammunition and explosives, drum burners, and combination systems (e.g., a hearth connected to a liquid injection unit).

OTHER INCINERATION-LIKE TECHNOLOGIES

In addition to the traditional incineration technologies, two incineration-like technologies for destroying wastes are currently in use.

Pyrolysis

Pyrolysis refers to technologies that accomplish thermal destruction in an oxygen-deficient atmosphere. Pyrolysis equipment is similar to conventional incineration technologies, with the obvious exception that it lacks a system for introducing air into the combustion chamber. Organic waste compounds are volatilized and partially decomposed by thermal reactions alone. Gases from the pyrolytic chamber then pass into a conventional chamber where they are combusted in the presence of excess air. One advantage of pyrolytic technologies is that emissions of particulates tend to be lower than do those from more traditional incinerators (8).

Three pyrolysis units are currently operating in the United States, and several others are planned (1).

Wet Air Oxidation

Wet air oxidation is a thermal destruction technology that oxidizes organic contaminants in water. The water modifies oxidation reactions so that they can occur at relatively low temperatures (350° to 650° F). Air is bubbled through the liquid phase, and the reactor vessel is maintained at a pressure high enough to prevent excessive evaporation (8).

Wet air oxidation is primarily applicable to aqueous waste contaminated with dissolved or suspended organic material. The organic content of wastes suitable for wet air oxidation is generally too low to make traditional incineration economical, but sufficiently high to sustain the reaction temperatures needed for oxidation. The technology has been used successfully to treat a variety of aqueous wastes contaminated with nonhalogenated organic compounds, but it has been much less successful with halogenated compounds. Moreover, a secondary process is typically needed, because detoxification is incomplete (40 to 95 percent).

Figure 6 depicts a typical wet air oxidation system. Several units are currently operating in the United States.

USE OF AIR POLLUTION CONTROL AND HEAT RECOVERY EQUIPMENT

Equipment serving either of two additional functions can be (or is required to be) added to the basic systems described above. Such equipment includes devices to control the emission of air pollutants and devices to recover and use a portion of the energy released through incineration.[2]

Air Pollution Control Equipment

Air pollution control equipment is often required for land-based incinerators, particularly if wastes with significant ash or halogen content are to be incinerated. Such equipment consists of two components. The first is a quench chamber or heat exchanger to cool the gases leaving the combustion chamber. The cooling is necessary for efficient operation of air pollution controls located downstream.

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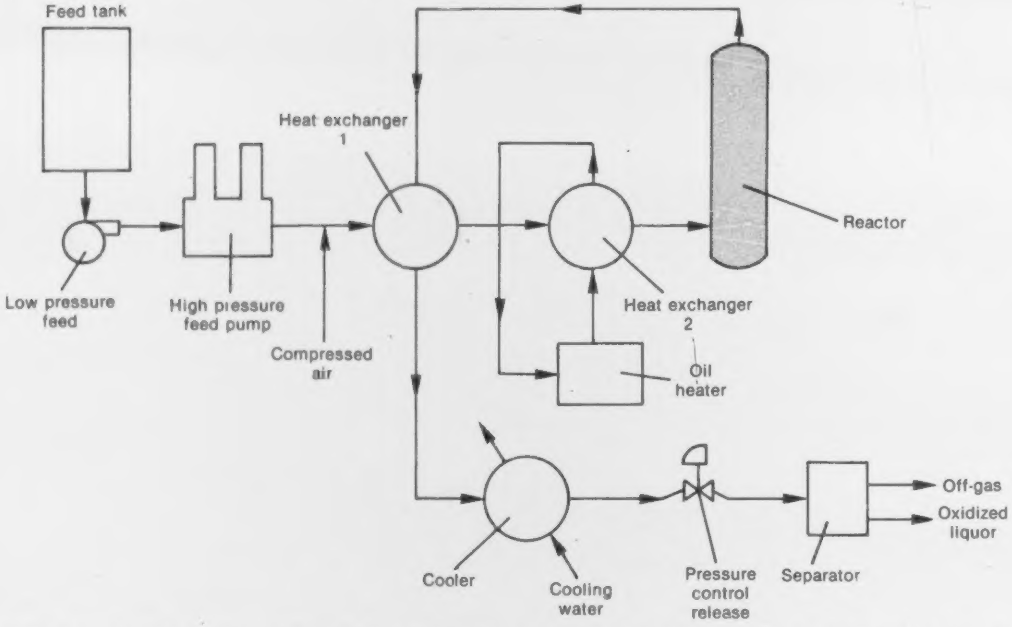
[2] This discussion is drawn primarily from refs. 1 and 3; these sources should be consulted for additional information.

Figure 6.—Wet Air Oxidation



SOURCE: Arthur D. Little, Inc., *Overview of Ocean Incineration*, prepared by J.R. Ehrenfeld, D. Shooter, F. Ianazzi, and A. Glazer for the Office of Technology Assessment (Cambridge, MA: May 1986).

The second component includes one or more scrubbers for actually cleaning the gases. Major commercial incineration facilities typically remove particulates by using wet or dry electrostatic precipitators, venturi scrubbers, or, less commonly, fabric filters. Removal of gaseous pollutants, including corrosive acid gases, usually requires a wet scrubber, which neutralizes gases through contact with an alkaline liquid reagent. Operation of a wet scrubber requires installation of a mist eliminator downstream, to separate the flue gases from water droplets containing contaminants. (For a fuller discussion of scrubbers, see app. B in ref. 6.)

Both particulate and gaseous pollutant removal systems generate waste sludges that, along with ash residues, are typically handled as hazardous wastes and disposed of in hazardous waste landfills.

Energy Recovery Equipment

Energy recovery equipment is not required under current regulations but is sometimes installed on hazardous waste incinerators if it is deemed economically feasible and advantageous. Such equipment generally can only be installed *upstream* from air pollution control equipment, that is, prior to removal of corrosive gases or particulates. Incineration of wastes generating these products may damage or interfere with the operation of energy recovery equipment and, therefore, often precludes its use. Certain modifications have recently been introduced to partially alleviate these design restrictions.

Energy is generally recovered through the production of steam, which can be used to generate electricity, to drive machinery, or to provide heat. Alternatively, energy can be used to heat the air fed to the incinerator, thereby increasing combustion efficiency and reducing the need for auxiliary fuel.

Typical energy recovery equipment consists of watertube or firetube boilers capable of recovering 60 to 80 percent of the heat content of combustion gases.

PROFILE OF EXISTING HAZARDOUS WASTE INCINERATORS

This section, which is drawn largely from EPA documents, summarizes available information on the number, capacity, and characteristics of existing land-based hazardous waste incinerators. OTA has found that these data are incomplete and only provide rough estimates, even of seemingly straightforward statistics, such as the number of permitted hazardous waste incineration facilities currently operating in the United States. No reliable national database containing such information currently exists. Moreover, the number and permit status of incineration facilities is constantly changing, as permits are processed or facilities open or shut down in response to various regulatory or economic factors.

Despite these deficiencies, data derived from several sources can be used to develop a profile of existing facilities.

Number of Incineration Facilities

EPA has estimated that about 240 to 275 operating hazardous waste incineration facilities exist in the United States.[3] This estimate emerged from several independent studies, including those based on the Westat national survey (10), interviews with incineration manufacturers, a survey of RCRA Part A permit applicants listed in the EPA Hazardous Waste Data Management System, and data from EPA Regional Office permit files.

As of July 1982, EPA had identified 271 hazardous waste incineration facilities using 352 operational incineration units (3). Based on 1985 permit data, however, this estimate was revised downward, to about 240 facilities using about 310 incineration units (5). The reduction in part reflected the fact that some facilities ceased operations instead of securing final Part B RCRA permits.[4]

Table 9 presents two estimates of the number of incinerators of each design that were in use in 1981 (3). One estimate (shown in column A) was derived from interviews with incinerator manufacturers regarding the number and type of units sold in the United States. The other (column B) was extrapolated from partial data obtained from applications for RCRA Part A permits. These estimates generally agree regarding liquid injection and hearth in-

Table 9.—Two Estimates of the Number of Land-Based Incineration Units Operating in the United States

	Estimate A[a]		Estimate B[b]	
	Number of units	Percent of total	Number of units	Percent of total
Liquid injection	219	65%	213	61%
Hearth (total)	70	21	75	21
Hearth (with liquid capacity)	—	—	(44)	—
Hearth (solids only)	—	—	(31)	—
Rotary kiln (total)	37	11	17	5
Rotary kiln (with liquid capacity)	—	—	(15)	—
Rotary kiln (solids only)	—	—	(2)	—
Fluidized bed	9	3	5	1
Other or unspecified	—	—	42	12
Total	335		352	

[a] Estimate A is derived from interviews with incinerator manufacturers regarding the number and type of units sold in the United States.

[b] Estimate B is based on extrapolation from partial data obtained from RCRA Part A permit applicants.

SOURCE: E. Keitz, G. Vogel, R. Holberger, et al., *A Profile of Existing Hazardous Waste Incineration Facilities and Manufacturers in the United States*, EPA No. 600/2-84-052, prepared for the U.S. Environmental Protection Agency, Office of Research and Development (Washington, DC: 1984).

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[3] This estimate excludes industrial boilers and furnaces, which are not considered incinerators under current regulations. These facilities are numerous in the United States, and they currently account for the destruction of substantially more hazardous waste than do incinerators (see ch. 4).

[4] Complicating matters further, OTA recently obtained a computer printout from the Hazardous Waste Data Management System of incinerator facilities that had submitted permit applications as of May 1986. This source listed a total of 274 incineration facilities with pending applications, but it did not provide any information concerning incinerator design or commercial status. In this discussion, the data from this source will be used as the most current available data.

cinerators but differ significantly regarding rotary kilns. (Note that these estimates were derived from 1981 data; the total number of units has changed since 1981, but revised data for the distribution among different designs are not available.)

The data from Estimate B in table 9 indicate that almost 80 percent of hazardous waste incinerators have some capacity for burning liquid wastes.

Data on the use and nature of **air pollution control equipment** on land-based incinerators are scant. Based on data obtained from applicants for RCRA Part A permits, EPA (3) estimated that about 45 percent of existing incinerators have some form of air pollution control equipment. About 37 percent of existing units use some type of scrubber. Large incinerators and those employing higher temperatures and longer residence times were more likely to have air pollution control equipment.

EPA (3) also found that only about 22 percent of existing incinerators used **energy recovery equipment**. Energy recovery equipment is more commonly found on incinerators burning liquids, on larger incinerators, and on incinerators operating on a continuous basis.

Only six incineration facilities are currently permitted to incinerate PCBs, as provided under the Toxic Substances Control Act. See box B in chapter 3 for a more detailed discussion of PCB incineration.

Location of Incineration Facilities

This section considers both the regional distribution and the commercial status (i.e., onsite versus offsite) of existing incineration facilities. For the 274 facilities for which data were available, figure 7 indicates the number of facilities located in each State and EPA Region. Table 10 presents the commercial status of the 227 facilities whose status was indicated in reference 3.

Several conclusions can be drawn from these data on regional distribution. First, as was true for incinerable waste generation, the distribution of hazardous waste incinerators is concentrated in particular States and regions. (For example, as shown in figure 7, EPA Regions V and VI each contain about one-fifth of all facilities. Texas alone accounts for almost one-eighth of all facilities.) Second, the Northwestern United States, in general, contains few incineration facilities, and EPA Region VIII contains no *commercial* facilities. Finally, the great majority (80 percent) of existing hazardous waste incinerators are private facilities located onsite. No correlation is apparent between onsite or offsite incineration and regional distribution.

EPA also examined the sources of waste burned by the incinerators covered in its survey. Of the respondents, 77 percent identified waste they incinerated as having been generated onsite. Of the 23 percent that reported handling waste generated offsite, 90 percent were commercial incinerators (3).

Incinerator Capacities and Operating Characteristics

Existing incinerators have been further characterized with respect to their capacity for liquid and solid wastes and the temperatures and residence times attained under typical operating conditions.

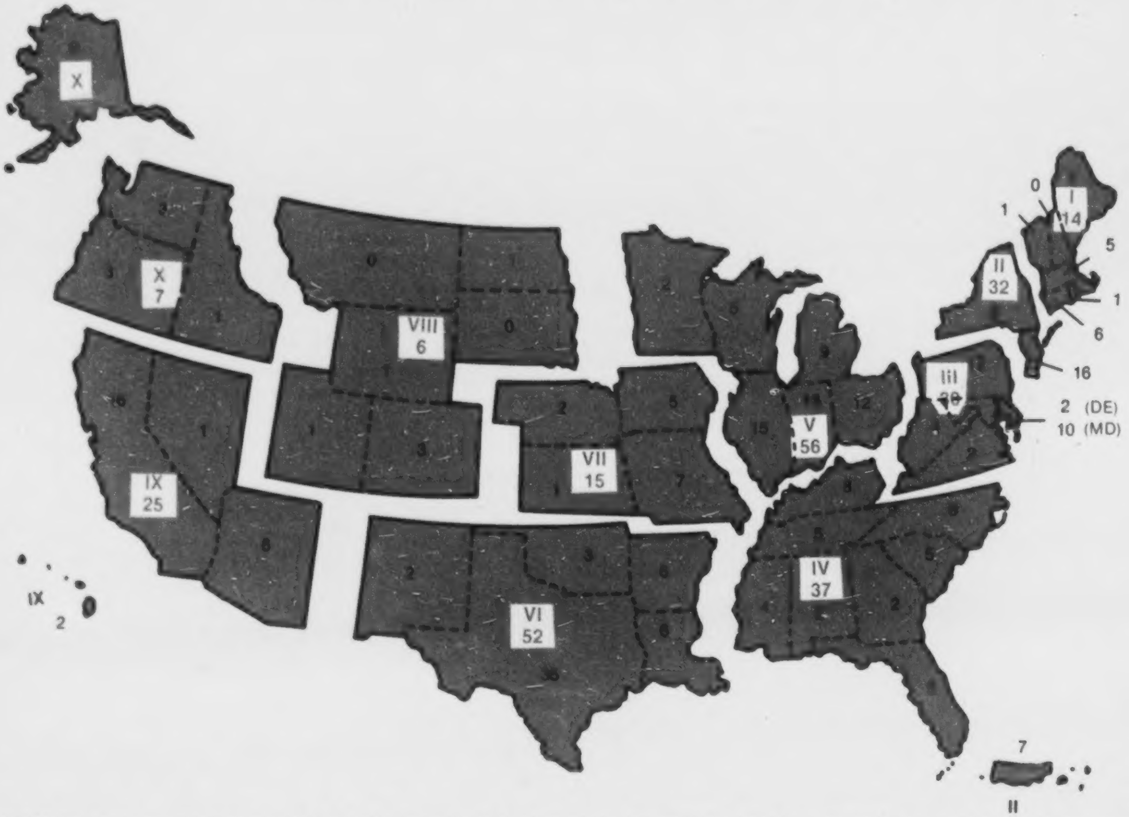
Capacity

For 180 of the incinerators surveyed by EPA (3), capacity for liquid wastes was specified. Figure 8 shows the range of capacities.

According to these data, the capacities of two-thirds of existing incinerators for liquid wastes are below 300 gal/hr (2,500 lbs/hr). The median capacity for liquid wastes is 150 gal/hr (1,250 lbs/hr). Similar data for incinerators burning solid wastes revealed a median capacity of less than 80 gal/hr (650 lbs/hr), or about half of the median for liquids. Assuming that the facilities were operated at an average of 55 percent capacity, as estimated by EPA (9), the median capacities would translate into *annual* throughputs of about 1,400 metric tons for solid wastes and 3,000 metric tons for liquids.

These data can be compared to the burning rate for liquid wastes incinerated at sea. Each of the incinerators on the Vulcanus ships has a capacity of about 1,650 gal/hr, or about 11 times the median for land-based incinerators. The Apollo ships are designed to have an even greater capacity, about 2,750 gal/hr per incinerator (7). Only 2 percent of all land-based incinerators have a reported capacity greater than 2,000 gal/hr, and about 4 percent have capacity greater than 1,000 gal/hr.

Figure 7.—A Regional Profile of Land-Based Hazardous Waste Incineration Facilities: Number of Facilities Located in Each State and EPA Region (Total of 274 facilities)



SOURCE: Data based on a computer printout from the Hazardous Waste Data Management System of incinerator facilities that had submitted permit applications as of May 1986.

The large commercial rotary kiln incinerators in use today have *annual* throughputs of about 20,000 to 35,000 metric tons of mixed wastes,[5] whereas existing ocean incineration vessels could each burn 50,000 to 100,000 metric tons of liquid wastes annually (refs. 2,9; and data from incineration vessel owners).

Combustion Zone Temperature and Residence Time

According to EPA (3), the average combustion zone temperature in those incinerators for which data were available was 1,820 ± 225 ° F (993 ± 107° C). For liquid injection incinerators, the average was slightly higher, 1,857 ± 224° F (1,014 ± 107° C). In both cases, the median temperature was about 1,800° F. Liquid injection incinerators generally operate at higher temperatures than do rotary kilns, because the former do not require as much excess air to atomize and combust liquid wastes.

With respect to residence time, EPA data indicate that about half of the incinerators for which data were provided had residence times of 2 seconds or longer, and only about 15 percent had residence times under 1 second. Liquid injection incinerators had a similar distribution.

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[5] If these incinerators were to burn only liquid wastes, the capacity would be considerably higher.

Table 10.—Commercial Status of Land-Based Incineration Facilities, by EPA Region

EPA region	Private	Commercial	Government[a]
I	8	1	1
II	20	2	0
III	19	3	1
IV	33[b]	9	4
V	24	4	1
VI	53	6	3
VII	7	1	0
VIII[c]	4	0	2
IX	9	2	3
X[c]	3	2	2
Total[d]	179	30	17
(percent)	(79%)	(13%)	(8%)

[a] Government facilities are generally special units used for ammunition disposal or research.

[b] This number includes one private facility that engages in some commercial incineration.

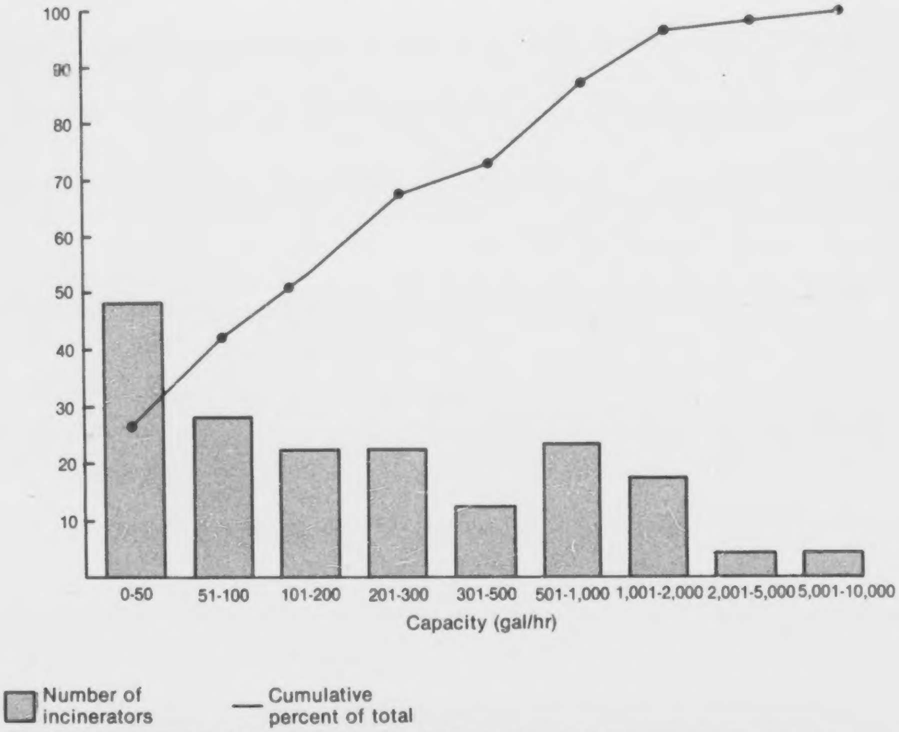
[c] These estimates are derived from Hazardous Waste Data Management System (HWDMS), 1986. In these cases, it was possible to discern the commercial status of the small number of facilities.

[d] The total here does not equal that in figure 7 due to the use of different sources for the data. HWDMS data used in figure 7 for the most part did not indicate the commercial status of the facilities it listed.

SOURCE: E. Keitz, G. Vogel, R. Holberger, et al., *A Profile of Existing Hazardous Waste Incineration Facilities and Manufacturers in the United States*, EPA No. 600/2-84-052, prepared for the U.S. Environmental Protection Agency, Office of Research and Development (Washington, DC: 1984).

When considered together, the data indicate that higher combustion zone temperatures and longer residence times appear to be correlated. Residence times greater than 2 seconds were reported for three-quarters of those incinerators operating above 1,900° F but for only one-quarter of those operating below 1,900° F.

Figure 8.—A Profile of the Capacity of Land-Based Incinerators for Liquid Wastes



SOURCE: E. Keitz, G. Vogel, R. Holberger, et al., *A Profile of Existing Hazardous Waste Incineration Facilities and Manufacturers in the United States*, EPA No. 600/2-84-052, prepared for the U.S. Environmental Protection Agency, Office of Research and Development (Washington, DC: 1984).

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Ocean Incineration Technology

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Chapter 6

Ocean Incineration Technology

EXISTING AND PLANNED VESSELS

Ocean incineration technology has been used on a much smaller scale than has land-based incineration or any other major technology for managing hazardous wastes. Two incineration vessels are currently operating, primarily in Europe;[1] two more are fully or partially built but not yet employed; and plans for constructing others have been offered by several companies. The combined waste handling capacity of all of these vessels could accommodate only a small portion of the hazardous waste generated in the United States.

Generally speaking, a single technology has been used or proposed for ocean incineration. All existing or planned ocean incineration vessels use liquid injection technology, and are intended to incinerate only liquid organic wastestreams. Table 11 summarizes relevant data for all existing, under-construction, and planned incineration vessels. Of these, the only foreign-owned vessel is the German *Vesta*, which operates in the North Sea.

Although all of these vessels share features intended to respond to the unique needs and constraints of ocean incineration, they differ in several important respects. This chapter examines ocean incineration technology and wastestreams, as well as associated aspects of operations, such as requirements for port facilities. The chapter also compares and contrasts the various existing and proposed technologies for ocean incineration. For a comparison of land-based and ocean incineration technologies, see chapter 7.

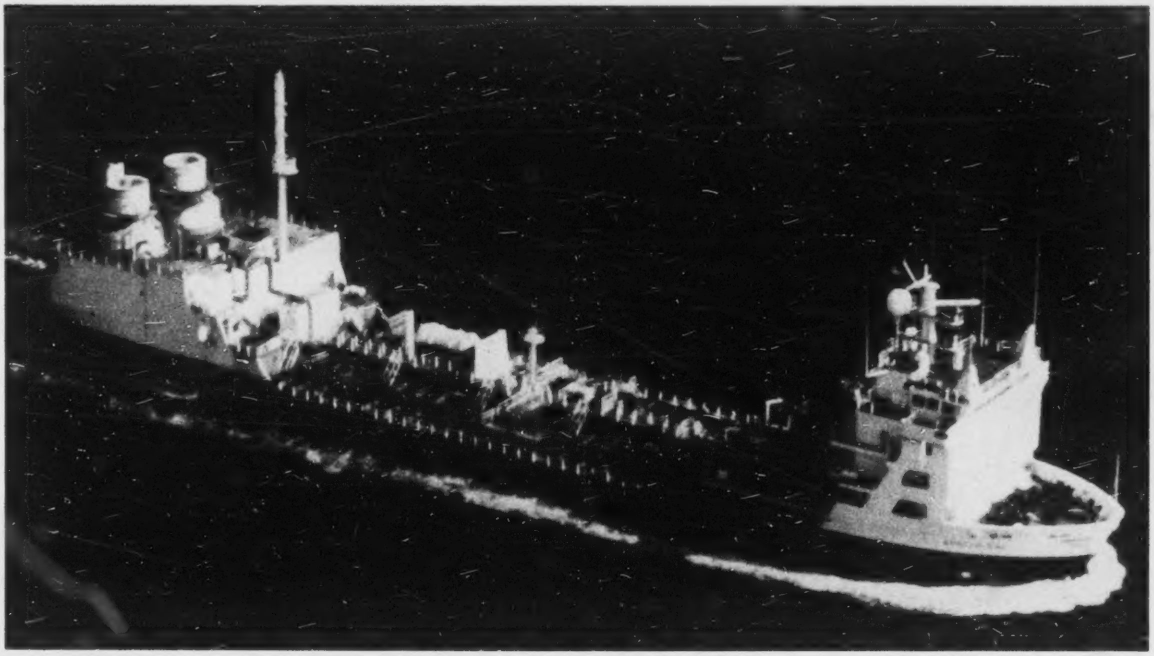

Photo credit: At-Sea Incineration, Inc.

The *Apollo I* incinerator ship, launched in 1985 but never used for incineration of hazardous wastes.

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[1] The two vessels are the *Vulcanus II* and the *Vesta;* the *Vulcanus I* is operational but not currently active.

Table 11.—Characteristics of Existing and Proposed Incineration Ships

	Vulcanus I	*Vulcanus II*	*Apollo I*	*Apollo II*	SeaBurn vessel	EOS vessel	*Vesta*
Owner/operator	Waste Management, Inc./ Ocean Combustion Services		Tacoma Boat/ At-Sea Incineration, Inc.[a]		SeaBurn, Inc./ Stolt Nielsen	Env. Oceanic Services Corp.	Lehnkering AG
Current status	Operating in Europe	Operating in Europe	Completed	Under construction	Planned	Planned	Operating in Europe
Type of vessel[b]	Converted cargo ship type II	Incinerator ship type II	Incinerator ship type II	Incinerator ship type II	Oceangoing barge and tug type I	Small supply ship type II	Incinerator ship type II
Number of incinerators	2	3	2	2	4	1	1
Incinerator orientation	Vertical	Vertical	Vertical	Vertical	Horizontal	Horizontal	Vertical
Burner type	Rotary cup	Rotary cup	Air nozzle	Air nozzle	Steam nozzle	Steam nozzle	Rotary cup
Cargo mode	8 tanks below deck	8 tanks below deck	12 tanks below deck	12 tanks below deck	144 containers (stainless steel intermodal containers stored above deck)	16 containers	9 tanks below deck
Total capacity (× 1,000 gal)	800	800	1,300	1,300	720	80	290
Waste feed rate (gal/hr)	3,300	4,950	5,500	5,500	3,240	?	≈ 2,640
Full load burn time (days)	10.1	6.7	9.9	9.9	9.3	?	4.6
Emission controls	—	—	—	—	Seawater quench/scrubber		—
Required infrastructure	Existing	Existing	Integrated	Integrated	None	None	Existing

[a] Tacoma Boat is currently reorganizing under Federal Bankruptcy Laws; At-Sea Incineration, Inc., defaulted on payment of guaranteed loans initially granted and recently paid off by the U.S. Maritime Administration.

[b] Type II chemical tankers must have double hulls and double bottoms, and must store wastes in several different compartments to reduce cargo loss in the event of an accident. Design standards for type I vessels include these and additional requirements. The proposed Ocean Incineration Regulation (50 FR 8225, Feb. 28, 1985) and U.S. Coast Guard regulations (46 CFR 172) require that incineration vessels be at a minimum type II.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report I: Description of Incineration Technology," *Assessment of Incineration as a Treatment for Liquid Organic Hazardous Wastes* (Washington, DC: 1985); and W. Lankes, "Incineration At Sea: Experience Gained With the M/T Vesta," in *Wastes in the Ocean*, vol. 5, D.R. Kester, et al. (eds.) (New York: John Wiley & Sons, 1985), pp. 115-124.

WASTESTREAM CHARACTERISTICS

Typical liquid hazardous wastestreams are complex mixtures of many chemical compounds. For ocean incineration in particular, most shiploads are expected to consist of heterogeneous mixtures derived from several or many sources and processes. Wastestreams are usually characterized with respect to a number of parameters. The viscosity of the waste must be sufficiently low to allow it to be pumped and introduced into the incinerator in small droplets. The heating value (i.e., energy content) of the waste feed must be sufficiently high to heat incoming waste to its ignition temperature, to provide the energy needed for oxidation, and to maintain combustion. The heating value of a waste generally decreases as water content increases and as the proportion (percent by weight) of chlorine present in organic compounds increases. Therefore, liquid wastes are usually blended to produce optimum values for energy content, chlorine and water content, and viscosity. Virtually all wastes, even relatively homogeneous ones, require some blending before incineration to ensure proper consistency and flow.

INFRASTRUCTURE AND LOGISTICAL SUPPORT SYSTEMS

The various ocean incineration vessels differ in how much they rely on waste preparation, storage, handling, and transfer facilities on shore. Three general categories of logistical systems have been identified (7,8).

No-Infrastructure System

Under this system, waste handlers make minimal use of fixed facilities. Wastes accumulate where they are generated or handled, stored in truck or rail tanks or in portable containers. When full, the tanks or containers are transported to existing port transfer facilities not dedicated solely to ocean incineration operations. Wastes are pumped or are lifted in containers onto the vessel. Any blending of wastes from different sources occurs only on board, as they are fed to the incinerator. Wastes from different storage tanks are fed sequentially or simultaneously, to provide the best burning mixture.

SeaBurn, Inc., and Environmental Oceanic Services Corp. plan to use a variant of this design. They would use the sealed 5,000-gallon stainless steel intermodal containers (see discussion of containerization below) to transport wastes from their sources to the the vessel, avoiding the need for any dockside handling of uncontainerized wastes.

Existing Infrastructure System

Under this system, waste handlers use port facilities not dedicated solely to ocean incineration. Blending, preparation, and storage functions are carried out at existing, centralized facilities that are entirely separate from the port facility.

Waste Management, Inc., plans to employ such a system (or to develop an integrated system; see below) to support *Vulcanus* operations in the Gulf. Under the existing system, liquid wastes would be transported from generators to its testing, blending, and storage facility at Emelle, Alabama. Blended wastes would be loaded onto trucks for transport to dockside, and then pumped directly from the trucks to the vessel.

Integrated System

Under this system, waste handlers use specialized port facilities designed primarily for ocean incineration. The facility receives wastes directly from generators and maintains onsite testing, blending, and storage capability for both containerized and tanked wastes.

At-Sea Incineration, Inc., proposed using such an integrated port facility to support operation of its *Apollo* vessels. Waste Management, Inc., is considering developing such a facility, in lieu of or in addition to its existing facility at Emelle, Alabama.

TECHNICAL COMPARISON OF DESIGNS FOR OCEAN INCINERATION

One major theme of the debate over ocean incineration is whether a *best-available-technology* (BAT) approach is needed or desirable and, if so, whether existing vessels represent BAT (see ch. 2). The various designs for ocean incineration vessels differ in several respects that directly bear on the nature and potential safety of their operations. The Environmental Protection Agency has not yet thoroughly evaluated the various designs; such an evaluation must be undertaken if the BAT question is to be resolved.

Given its limited mandate in this study, OTA has *not* attempted to develop a comprehensive comparative evaluation. Rather, the following discussion identifies particular design and performance features that would probably be central issues in such a comparison. By reference to table 11, the specific vessels to which this discussion applies can be identified.

Containerization Versus Bulk Storage and Transfer

The most obvious difference between existing and proposed designs for ocean incineration systems is how cargo is handled and transferred. Two companies have proposed systems based on a containership concept that would employ 5,000-gallon stainless steel **intermodal tank containers**. Intermodal (IM) containers are increasingly used for all types of cargo throughout the world. An estimated 20,000 IM tank containers designed specifically to carry liquid commodities are in use worldwide (3). As the name implies, IM containers can be transported via rail, truck, barge, and ship. Standardized twistlock mechanisms on containers and on vehicle chassis are designed to ensure that containers are adequately secured during transport.

In specifically applying the containership concept to ocean incineration, waste generators or handlers would fill and seal tank containers and would transport them by truck or rail to port facilities for loading onto barges or ships. No blending or other handling of waste would occur at the ports. IM tank containers would be mounted on or above deck and their wastes individually pumped to a feed tank directly connected to the incinerator. Following cleaning, tank containers would be returned to generators for further use.

The containership concept differs from existing ocean incineration systems, which use more conventional tank trucks and tank farms for land transportation and storage, and large bulk tanks (about 100,000 gallons each) to hold waste onboard the vessels. As described above, waste blending and transfer facilities on land are an essential link in such systems.

The relative advantages and disadvantages of these two approaches need to be evaluated for all phases of incineration operations, beginning with waste generators and ending with handling during and after shipboard incineration. Advantages and disadvantages of IM containers are discussed below, for each of several phases of incinerator operation: land transportation, handling, and transfer; marine transportation; and waste incineration. First, however, the reader must recognize several assumptions that apply to this analysis.

In the following discussion of advantages and disadvantages, the intermodal approach is implicitly compared with the more conventional bulk handling system used by all existing incineration vessels. It is important to recognize that particular features of an individual company's operation may greatly affect the extent to which these advantages or disadvantages are applicable. The discussion is therefore oriented towards a "generic" operation, and wherever possible, relevant information specific to a particular operation is also presented.

In addition, both the bulk and intermodal tank approaches to handling hazardous cargoes are already widely used. The U.S. Coast Guard believes that both approaches can be, and are being, carried out safely under appropriate regulation. The Coast Guard has further indicated that solutions are available to the problems that are identified below, and can be addressed through proper regulation, thereby rendering both approaches fully viable.[2] The intent of the discussion, therefore, will

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[2] These comments were received through the review of a draft of this report by the U.S. Coast Guard.

SeaBurn
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Photo credit: SeaBurn, Inc.

Stainless steel intermodal tank containers, which typically carry about 5,000 gallons, can be transported via rail, truck, barge, or ship. The supporting framework reduces the risk of breaching the tank in the event of an accident and provides for securing of the tank to specially designed chassis during transport.

be to point out features of each approach that are advantageous or that may require additional regulation in order to ensure safe operation.

Land Transportation, Handling, and Transfer

Advantages:

- Tank containers are sealed at the site of generation and before any transportation, so that wastes do not need to be transferred later on land or at the port.
- The intermodal nature provides for flexibility in transport, because IM tank containers can travel to port facilities by truck, rail, or barge.
- No special facilities are required at the port, and individual IM tank containers can be stored still attached to their chassis while awaiting the arrival of the incineration vessel, facilitating their movement in the event of an emergency.
- The IM tank container is encased in a rigid metal protective frame that substantially reduces the risk of breaching the tank in the event of a rail, highway, or terminal accident.
- A large and growing international network for handling and transporting IM containers is available.
- Wastes from different generators are not mixed or blended before they are incinerated, allowing the identity and source of a waste to be traced in the event of a spill.

Disadvantages.—Although there appear to be several clear advantages with respect to the IM tank container itself, transport of these containers, particularly by truck, poses several problems.[3] These problems are related primarily to the fact that there is an insufficient number of chassis designed to transport IM tank containers in a manner that maximizes over-the-road stability and complies with bridge laws that limit the vehicle weight per axle and per wheelbase.

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[3] Another OTA assessment (9) examines hazardous materials transportation in detail and evaluates the relative safety, performance, and regulation of intermodal and other bulk liquid containers. Much of the discussion of land transportation using IM tank containers presented here is drawn from that analysis.

- The chassis most commonly used today that is designed specifically to carry IM containers is 20 feet in length and equipped with corner twistlocks; however, for most liquids, a fully loaded IM tank container mounted on such a chassis violates bridge laws in most States. The option of partially filling the tank is not viable, since it can lead to sloshing of the liquid contents and instability on the road. Use of a 40-foot chassis with the IM tank container centrally mounted using twistlocks solves these problems; however, the number of such chassis (estimated to be only about 400 in the entire United States) is far less than the number of IM tank containers currently in use.
- The size, shape, and height of IM tank containers are such that, even when mounted legally on the standard 20- or 40-foot chassis, they can be inherently unstable: the high center of gravity greatly increases the potential for roll-over. A specially designed IM chassis called a "low boy" addresses this concern, and is widely used in Europe, but fewer than 100 of these chassis (40-foot, center-mount, and low boy) are in use in the United States.
- Although the number of standard 20-foot chassis possessing twistlock mechanisms is sufficient to accommodate the IM tank containers currently in use in the United States, their use on the highway violates bridge laws in many States. This situation commonly results in the transport of IM tank containers on flatbed trucks, "secured" by wrapping with chains. This practice is entirely legal under current Department of Transportation regulations, even though it has been denounced by some trucking industry representatives and has resulted in a number of accidents involving hazardous materials (for example, see ref. 2).

These problems appear to have a straightforward technical solution: required use of 40-foot low boy chassis for over-the-road transport of loaded IM tank containers. Indeed, SeaBurn, Inc., has indicated that it plans to use the 40-foot low boy chassis. SeaBurn intends to have a sufficient number of these chassis manufactured to support its operation, and to dedicate these chassis exclusively to such use in order to preclude unauthorized methods of handling its IM tank containers.

Marine Transportation

The containership concept appears to offer several advantages over bulk transport in the marine transportation phase of ocean incineration. The advantages include the following:

- The relatively small volume of waste in each container should limit the size of a spill in the event of an accident. Many individual tank containers would have to rupture to approach the size of a release that could be expected from the rupture of one large bulk cargo tank.
- Because individual IM tank containers could be relatively easily salvaged, they would facilitate the retrieval of waste lost overboard.
- IM tank containers would be stowed above deck, and hence above water line. In addition, an on-deck spill collection system will be utilized. These features would facilitate inspection and leak detection and would reduce the likelihood that leaks would contaminate bilge water or the marine environment. The greater ventilation above deck would reduce the possibility of explosions caused by buildup of reactive gases.

Waste Incineration

In contrast to the advantages of using IM tank containers with respect to marine transportation, their use may pose significant disadvantages relative to bulk storage when considering the incineration operation itself. These disadvantages are all related to the large number of individual tanks involved:

- Because wastes are not blended before being loaded onto the vessel, a potentially enormous burden of waste analysis may be involved. Under the proposed Ocean Incineration Regulation, separate sampling and analysis will be required for each of the many individual tanks, before they are accepted by the permittee and again before they are incinerated. Verification by EPA that only permissible wastes are accepted for ocean incineration will become equally burdensome.

- The potential exists for incompatible wastes to come into contact when tank containers are switched. Accurate information regarding the contents of each container and constant control over the sequence in which tank containers are connected for pumping to the incinerator will be essential, to a much greater degree than would be required of the bulk storage approach.
- The reduction in the need for waste handling on land offered by the IM mode is reversed during the incineration operation itself. Frequent container switching (on the order of every few hours) will be required, increasing the potential for spills or exposure of the crew to waste materials.
- Whether and how the frequent switching of containers would affect incinerator performance or necessitate greater surveillance has not been adequately investigated. For example, ensuring consistency in waste destruction efficiency when switching from a high-energy waste to a low-energy waste would probably require adjustments in waste feed rate, use of auxiliary fuel, air flow, and other parameters.

Despite the clear differences between the bulk and containerized modes with regard to handling and incineration, the proposed Ocean Incineration Regulation contains no provisions specifically addressing containerized wastes. Provisions governing tank containers have been developed internationally and are incorporated into the London Dumping Convention's Technical Guidelines for Ocean Incineration.

Again, it is important to acknowledge that technical and regulatory solutions exist, or can be developed, to address the potential problems associated with both the bulk and containerized approaches, and to provide for their use to full advantage. The above discussion is intended to highlight areas where further attention may well be needed, rather than to detract from the merits of either approach. Based on OTA's limited analysis of the containership concept in relation to bulk transport, further study will be necessary to determine whether either approach provides a clearly superior technology for waste handling.

Self-Propelled Versus Barge Vessels

One company has proposed using an ocean-going barge-tug combination for ocean incineration. A total of one hundred and forty-four 5,000-gallon IM tank containers and up to four incinerators would be mounted on the barge. Such a vessel would have a shallow draft, which would allow it access to virtually any port facility.

Concerns have been raised about the relative safety and maneuverability of a barge system. Unfortunately, data that can be used to evaluate the safety of the type of ocean-going barge proposed for use in ocean incineration are largely unavailable. The U.S. Coast Guard maintains a database that records all reported hazardous materials spills to U.S. waters (10). Data for 1982 and 1983 indicate an accident rate for tank barges double that for tank ships. These data include barges of all types used to carry oil or hazardous substances, however, including those operating on rivers or other inland waters. Indeed, with respect to both the number of accidents and the quantities of material released, the vast majority involved oil released to inland waters. For spills involving *hazardous* substances rather than oil, the number of releases was two-fold higher for tank barges, but the quantities released were actually slightly higher for tank ships.

Several features of the ocean incineration barge proposed by SeaBurn, Inc., should greatly reduce the risk of a release of waste in the event of an accident, and are not reflected in the above statistics. First, the barge would be a *Type I* chemical tanker, which exceeds the *Type II* cargo containment requirements applicable to ocean incineration vessels.[4] According to SeaBurn, Inc., no other such barges currently exist in the world's fleet. Second, the proposed barge is ocean-going and has a ship's bow, unlike the barges involved in the vast majority of reported accidents. Given these and other features, SeaBurn, Inc., argues that its barge will be in a safety class all its own.[5]

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[4] Coast Guard regulations for chemical carriers specify three levels of cargo containment systems, Type I affording the highest degree of containment. See 46 CFR 172 for a description of these construction requirements.

[5] V.G. Grey, President, SeaBurn, Inc., personal communication, May 16, 1986.

As proposed, the SeaBurn barge would be towed behind an ocean-going tug, a feature which somewhat reduces its maneuverability relative to existing ocean incineration vessels possessing bow thrusters. However, the U.S. Coast Guard indicates that a barge-tug system can be operated safely, even in confined areas, particularly when accompanied by the other navigational controls (e.g., a moving safety zone) that are to be applied to ocean incineration vessels.[6]

Despite the factors discussed above, regulations governing construction, inspection, and other aspects of an ocean incineration system employing a towed barge should be carefully examined to ensure that the requirements are adequate and commensurate with those applicable to self-propelled systems.

Seawater Scrubbers

Existing ocean incineration systems are designed to vent combustion gases directly upwards into the atmosphere, which raises concerns about the potential for subsequent adverse impacts on the marine environment and at least the nearest shorelines. As an alternative, two companies have proposed a system in which combustion gases would pass through a scrubber-like device prior to discharge. A deluge of seawater would physically wash the exhaust stream. In contrast to a true scrubber, however, the seawater scrubber would immediately discharge the untreated scrubbing effluent into the ocean. Thus, the scrubber would alter the location and nature, but not the quantity, of the discharge to the marine environment.

A seawater scrubber would alter incinerator emissions in two major respects, by affecting both the partitioning and the temperature of emissions. Each of these differences offers potential advantages and disadvantages (see below).

Although a seawater scrubber would greatly affect the nature of incinerator emissions, data are currently insufficient for determining whether the addition of seawater scrubbers to ocean incineration vessels would provide any improvement over the technology presently employed. Further study may provide a basis for such a determination in the future.

Partitioning of Emissions

A seawater scrubber would divide emission components into two parts: those discharged in the scrubbing effluent; and those not removed through scrubbing and therefore emitted to the atmosphere. Acidic gases (typically hydrogen chloride) would be expected to be mostly neutralized during the wash, because of the natural buffering capacity of seawater. Any residual acid would be rapidly neutralized after the effluent was discharged to the ocean. In addition, during the scrubbing, some of the particulate and organic components of the emissions would become dissolved or become suspended in the effluent.

A seawater scrubber would significantly reduce the quantity of contaminants emitted to the atmosphere, but would discharge contaminants into the ocean at much higher concentrations than those resulting from contact of an unscrubbed plume with the ocean surface (12).

Plans call for the scrubbing effluent to be discharged directly into the wake of the vessel to maximize mixing and dispersion of trace contaminants. Being warmer than ambient seawater, however, the scrubbing effluent would tend to remain at, or rise to, the surface (12). The potential for these concentrated and heated discharges to affect surface-dwelling organisms (including the so-called microlayer; see ch. 9) has not been examined.

In contrast, emissions from vessels not employing seawater scrubbers would disperse and settle out over the ocean surface, affecting a larger area, but introducing contaminants at lower concentrations.

Temperature of Emissions

Seawater scrubbers would also quench (i.e., cool) exhaust gases, reducing their exit temperature from about 2,500° F to below 300° F. This would have two practical effects on incinerator emissions. First, the plume would be less buoyant and would, therefore, not rise as far above the ocean surface. This effect would tend to decrease the time required for the plume to settle on the ocean surface, thereby decreasing the size of the affected area, but also increasing concentrations at the surface. As indicated previously, this increase in the concentration of incineration products would be expected to exert relatively greater effects on surface organisms residing in the smaller affected area.

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[6] These comments were received through the review of a draft of this report by the U.S. Coast Guard.

Second, because sampling of stack gases is complicated by the high exit temperatures as well as by the corrosivity typical of ocean incineration emissions, a scrubber might help to simplify emissions monitoring and reduce damage to sampling devices. On the other hand, sampling of emissions for particulates (see ch. 7) could become more difficult or impossible, because particulates might be washed out of the plume before they could be sampled. Significant quantities of unburned wastes or products of incomplete combustion (PICs) can be bound to such particulates after exhaust gases have cooled or condensed (1). In the absence of corrective measures, this effect could significantly compromise the reliability of sampling for the purposes of calculating a destruction efficiency.

Clearly, further research into the advantages and disadvantages of seawater scrubbers will be necessary to determine whether they represent best available technology. As discussed in chapter 1, based on available information, there appears to be little need for scrubbers on ocean incineration vessels if proper controls are placed over waste content and operating conditions.

Combustion Chambers

Existing and proposed technologies also differ with respect to the design and orientation of the combustion chamber itself. Existing vessels carry vertically mounted single-chamber incinerators, whereas two proposed designs would use horizontally mounted two-chamber units.

Proponents of the horizontal orientation argue that it is the only design that could accommodate a seawater scrubber and two combustion chambers, and that the design would also help to reduce plume altitude. Passage of wastes through two combustion chambers should at least theoretically increase residence time and enhance destruction efficiency. However, confirmation of these claims must await the development and testing of such an incineration vessel. Moreover, because two chambers are not considered necessary to achieve high destruction efficiencies of *liquid* wastes in land-based incinerators (see ch. 2), requiring their use in ocean incineration appears premature. Although EPA's reliance on performance rather than design standards does not negate the need for further investigation into combustion chamber design, it represents a reasonable regulatory approach at the present time.

Burner Types

Incinerator burners serve several important functions, including atomization (i.e., fine droplet formation) of wastes. The degree of atomization can be an important determinant of overall destruction efficiency because it affects the mixing rate of waste and air in the combustion zone. The ocean incineration vessels that are currently operating employ a traditional European-designed burner that atomizes incoming waste using a mechanical device (rotary cup or vortex). Those vessels recently built or planned for construction in the United States would use a U.S.-designed spray nozzle injection system for atomization. According to EPA, most land-based incinerators in the United States also employ the spray nozzle design (11).

Although the mechanical design for atomizing wastes is allowed by EPA, considerable controversy exists over the adequacy of its performance. Critics argue that the use of rotary cup burners is being discontinued or even prohibited because of insufficient atomization and excessive sensitivity to operating conditions like waste feed rate and vibration (see refs. 4 and 5, and other references therein). Proponents argue that studies specifically designed to assess the performance and degree of atomization of mechanical burners have found them comparable to other designs (1), and that the very short flame length generated by mechanical burners yields high combustion efficiencies (6).

According to EPA, insufficient data exist to correlate burner design with incinerator performance. Because burner design is only one of many factors (e.g., operating conditions, combustion chamber geometry) that affect incinerator performance, EPA has chosen to rely on performance rather than design standards in formulating both land-based and ocean incineration regulations (11). Thus, although further study of this issue is warranted, no consensus currently exists as to the best available technology for atomizing waste.

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Chapter 7

Comparison of Land-Based and Ocean Incineration Technologies

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Chapter 7

Comparison of Land-Based and Ocean Incineration Technologies

Although liquid organic wastes are currently managed in various ways, ocean incineration's primary competition and closest analog is land-based incineration. Therefore, it is important to compare and contrast their technical features, the nature and extent of their regulation, and their relative risks of environmental release and adverse impacts.

This chapter describes the nature of the combustion products arising from both land-based and ocean incineration and compares and contrasts their respective technical and regulatory requirements.

COMPOSITION OF INCINERATION PRODUCTS

The products resulting from incineration of hazardous waste, whether on land or at sea, can result from complete or partial thermal oxidation of waste components. The products can be grouped as follows: plume gases, residual parent compounds, products of incomplete combustion (PICs), metals and particulates, and solid residues. A brief description of each category is provided below.

Plume Gases

Total combustion of simple, nonhalogenated chemicals generates carbon dioxide and water as end products. If combustion is incomplete, carbon monoxide is also formed, and its level in emissions indicates the degree of incomplete combustion. Incineration of halogenated compounds generates acid gases (e.g., hydrogen chloride) and much smaller amounts of chlorine gas, in addition to carbon dioxide and water. The incineration of liquid wastes containing sulfur or nitrogen can produce a variety of sulfur oxides and nitrogen oxides.

Except for acid-forming emissions (dominated by hydrogen chloride), the Environmental Protection Agency (EPA) has not promulgated or proposed regulations limiting emissions of stack gases from hazardous waste incinerators. Relative to larger combustion sources like powerplants, the incinerators probably are a relatively minor source for most of these pollutants. For certain wastes or in certain geographic settings, however, hazardous waste incineration may contribute significantly to the risks posed by hazardous air pollutants.

Residual Parent Compounds and Products of Incomplete Combustion (PICs)

Parent compounds refer to those present in the original waste, a small fraction of which pass through the incinerator intact. PICs include both partially destroyed compounds and new chemical compounds not originally present in the wastes. PICs, which all types of combustion processes generate to some degree, include a wide range of compounds that are apparently synthesized during or immediately after combustion through chemical reactions or the recombining of molecular fragments.

PICs often bear little or no resemblance to the parent compounds from which they were derived; nor does the presence of a particular PIC necessarily correlate with the presence of a particular waste component. Very little is understood about how PICs are formed. They have been detected in the emissions from burning a wide range of materials, both hazardous and nonhazardous (e.g., municipal garbage, wood). The generation of PICs might be correlated with the level of oxygen present during incineration and with the completeness of combustion.

Both dioxin and dibenzofuran compounds, known to be highly toxic to humans and in the environment, have been identified among PICs produced from incinerating various materials; including municipal garbage. Our understanding of the public health significance of these emissions, or even their major sources, is far from complete.

The quantities of both residual parent compounds and PICs present in incinerator emissions vary with operating conditions, such as residence time, turbulence, and temperature. An EPA study of land-based hazardous waste incinerators (13) found that the concentrations of PICs in the stack gases were typically as high as the concentrations of parent compounds, but that both were rarely above 0.01 percent of the concentration of the parent compounds in the original waste. EPA's Science Advisory Board's analysis of available studies characterizing emissions from land-based incinerators, however, led the Board to conclude that:

> It is apparent that even with the uncertainties related to sampling efficiencies and inadequate chemical analyses, as much as 1 percent of the mass of the waste feed could exit an incinerator as compounds other than carbon dioxide, carbon monoxide, water, and hydrochloric acid. (16)

Under such conditions, a *total* destruction efficiency (DE) of only 99 percent would be achieved, even though a much higher DE would probably be measured under EPA's current definition (see discussion of DE in ch. 2).

With respect to ocean incineration, EPA was unable to detect any dioxins or dibenzofurans in stack emissions from the *Vulcanus* ships burning polychlorinated biphenyls (PCBs) or the defoliant Agent Orange. Questions have arisen, however, about the adequacy of sampling and analytic methodology employed during those monitoring efforts (see refs. 3,16; also see discussion of past U.S. burns in ch. 11).

EPA is currently devoting considerable effort to characterizing the PICs that result from hazardous waste incineration, and the Agency considers it a research priority. PICs are currently unregulated, although EPA proposed regulations under the Resource Conservation and Recovery Act (RCRA) in 1981 (46 FR 7684, Jan. 23, 1981). The proposed Ocean Incineration Regulation would not include any specific limits on the emissions of PICs, pending further study, but EPA is considering two approaches to their possible future regulation (see ch. 2, and proposed Ocean Incineration Regulation, 50 FR 8247, Feb. 28, 1985).

Metals and Particulates

These incineration products are the largely noncombustible, inorganic (mineral) remainder from the combustion of waste. In addition, substantial amounts of particulate matter are sometimes derived from the refractory firebrick lining of the combustion chamber, itself. How much of these products are generated depends on the type of waste incinerated; for example, the quantity of particulates from incineration of liquid wastes is generally significantly less than from incineration of solid wastes.

Because metals are not destroyed by incineration, those present in the waste feed are either deposited in ash residues or are emitted from the combustion chamber. Metals can be emitted in either a particulate (solid) or a volatilized (gaseous) state. Control strategies and environmental behavior vary considerably for these two forms and from metal to metal.

Incineration can alter the form and properties of metals in several important respects, which are discussed below.

Volatilization

The high temperatures typically employed in hazardous waste incinerators can volatilize heavy metals that are present in the waste; the degree of volatilization varies with the incinerator's operating conditions, and from metal to metal. Mercury, cadmium, and lead are generally considered most problematic because they are easily volatilized and are harmful if inhaled by humans. Although few data are available for hazardous waste incineration, one study examined the release of metals from incineration of sewage sludge at 1,600° F in a facility possessing air pollution control equipment (6). At least 20 percent of the lead and cadmium, and essentially all of the mercury, were emitted because of the scrubber's low efficiency at removing volatilized metals.

Solubility

Incineration can also alter the chemical form and solubility of metals found in wastes, thereby altering the metals' potential availability and routes of exposure to organisms or humans. For example, incineration might change a water-insoluble form of cadmium in an organic wastestream to a more soluble form; when the resultant ash is disposed of in a landfill, the cadmium would be more likely to leach into nearby groundwater. Incineration increases the water solubility of cadmium and copper and decreases the water solubility of chromium, nickel, and lead (4).

Bioavailability[1]

Incineration can alter the bioavailability of certain metals. The ability of living organisms to absorb and detoxify a particular metal greatly depends on the metal's chemical form. Because metal chemistry can be greatly altered by high temperature, the potential for incineration to increase or decrease the bioavailability of a metal must be considered. Although this problem has been insufficiently studied, some data indicate that incineration increases the bioavailability of arsenic and chromium (4).

Although emissions standards for specific metals do not exist, for either land-based or ocean incineration, EPA has limited the total allowable quantity of particulate material from land-based incinerators, which should lower emissions of those metals bound to particulate matter. For ocean incineration, EPA has proposed limiting the individual concentrations of particular metals in waste *accepted* for incineration and, furthermore, the concentrations of metals in the *final blended* waste, as a means of reducing the quantity of emitted metals (see next section). Many observers, however, have called for further characterization and regulation of actual metal *emissions*, based on their potential contribution to the risk posed by hazardous air pollutants (see chs. 2 and 9).

Solid Residues

These products include ash left behind in the combustion chamber and wastes generated when air pollution control equipment (e.g., scrubber sludges) is used.

Ash

The quantity and composition of ash resulting from incineration varies widely and primarily depends on the waste itself. For example, incineration generates substantially greater amounts of ash from solid wastes than from liquid wastes. Operating conditions can also influence the quantities of residuals. Ocean incineration typically produces very little or no ash, although periodic cleaning of the combustion chamber is necessary to remove slag.

Sludges and Dusts

Land-based incinerators that employ air pollution control equipment generate additional waste, including sludges and effluents (from the use of wet scrubbers) and dusts (from the use of dry scrubbers and other collection devices). The quantity of these additional wastes, which can be substantial (see ch. 8), depends on what waste is incinerated.

The existing regulations governing land-based incinerators (40 CFR 261.3(c)2) and those proposed for ocean incineration (50 FR 8268, Section 234.56(j), Feb. 28, 1985) define ash and pollution control residues as hazardous wastes and specify that they be handled as such. Under RCRA, however, a variance can be granted if the residue is shown to be nonhazardous (Sections 264.351 and 261.3(d)). Residues can also be delisted on a case-by-case basis by the EPA Administrator, under a provision of the 1984 RCRA Amendments.

The latter procedure may be used to delist residues from incineration of dioxin-contaminated materials generated by a mobile incinerator operating in Times Beach, Missouri (5). It may also be used to reclassify such residues as *hazardous*, rather than *acutely hazardous* (the designation given to all dioxin-contaminated materials). EPA sees such a step, which would significantly ease residue disposal requirements, as necessary to encourage incineration of dioxin wastes, but the reasoning is based on a controversial model of dioxin toxicity (7).

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[1] A *bioavailable* metal is one that can be taken up by a living organism and incorporated into its makeup or metabolic processes. Only certain metals, and only certain chemical forms of metals, are taken up, and the bioavailability of a particular metal also varies from one organism to another.

COMPARISON OF TECHNICAL AND REGULATORY REQUIREMENTS

This section summarizes and compares the various regulatory provisions that impose technical requirements on the use of land-based and ocean incineration. For land-based incineration, references are generally to EPA's Incinerator Standards for Owners and Operators of Hazardous Waste Management Facilities (46 FR 7666-7683, Jan. 23, 1981) and subsequent amendments (47 FR 27516-27535, June 24, 1982), developed under the statutory authority of RCRA. For ocean incineration, references are to the proposed Ocean Incineration Regulation (50 FR 8222-8288, Feb. 28, 1985), which was developed under the statutory authority of the Marine Protection, Research, and Sanctuaries Act (MPRSA).

Waste Analysis and Waste Limitations

An operating permit for either land-based or ocean incineration must specify what range of wastes an incineration facility has demonstrated its capability to satisfactorily treat. This range of wastes must be specifically tested in a trial burn. In specifying the wastes, the permit may limit waste composition, if necessary to meet performance or emissions standards. Some limitations are specific to a particular facility, whereas others apply to all incinerators.

Regulations for both land-based and ocean incineration require facility operators to perform periodic waste analyses in order to identify constituents to which performance standards apply (see below) and to ensure compliance with the terms of operating permits. The stringency of this requirement, however, differs considerably. For ocean incineration, a waste analysis would be required before each voyage; for land-based incineration, an analysis is required only when requested by EPA.

Wastes to be incinerated on land must be characterized with respect to the following:

- heat value,
- viscosity,
- physical form, and
- identification and approximate quantification of RCRA-hazardous organic constituents.

The waste description required for ocean incineration is somewhat more extensive than that for land-based incineration. In addition to those listed above, the following waste properties or components must be identified:

- moisture, solid, and ash content;
- specific gravity (density);
- presence of polychlorinated terphenyls;
- main inorganic constituents;
- halogens, sulfur, and nitrogen constituents; and
- other organic compounds not listed as hazardous under RCRA.

Limitations on chlorine content are commonly written into operating permits for land-based incinerators, in order to meet emissions standards or to stay within the operating limits of scrubbers. Solid or metal content may be similarly limited. If PCBs are to be incinerated, maximum concentrations of PCBs in the waste are specified for both land-based and ocean incineration.

Under the proposed Ocean Incineration Regulation, two additional kinds of waste limitations would be specified. First, EPA would specifically limit how much of each of the following 14 metals could be present in *waste accepted for incineration at sea*:

aluminum
arsenic
cadmium
chromium
copper
iron
lead
mercury
nickel
selenium
silver
thallium
tin
zinc

Concentrations would be limited to a maximum of 500 parts per million (ppm) per metal. No limits on the aggregate quantity of metals in the waste or in the emissions would be specified.

Second, certain metals (and potentially other substances) would be limited by a proposed environmental performance standard (see next section). Under the standard, concentrations of particular waste constituents in the *final blended waste to be incinerated* would be limited to amounts that would prevent the resulting mixture of incinerator emissions and seawater from exceeding marine water quality criteria.[2] EPA has determined that limits for mercury, silver, and copper would have to be below 500 ppm to meet marine water quality criteria (50 FR 51362, Dec. 16, 1985).

Both technical and regulatory distinctions between land-based and ocean incineration account for the differences in waste limitations and requirements for waste analysis. Limitations on chlorine content are not considered necessary for ocean incineration, because of natural seawater's ability to neutralize hydrochloric acid gas. This phenomenon is also the reason EPA would not require incineration vessels to carry air pollution control equipment. Because the lack of scrubbers would allow the emission of essentially all metals present in the waste, however, the metal content of wastes incinerated at sea would be strictly controlled.

The waste analysis requirements are more stringent for ocean incineration than for land-based incineration, partly because the two activities are regulated under entirely different statutes. Ocean incineration falls under the definition of ocean dumping specified in MPRSA. In general, international and domestic regulation of ocean dumping has strictly controlled the types of waste that could be dumped and has, therefore, mandated extensive waste analysis as a condition for obtaining permits.

Performance Standards

EPA's approach to regulating land-based and ocean incineration has relied primarily on standards for incinerator performance rather than standards governing incinerator design. Thus, any facility that possessed a combination of design features capable of meeting minimum performance standards would be eligible for an operating permit. This capability has typically been demonstrated by trial burns carried out prior to the granting of operating permits. For ocean incineration, EPA has proposed a combination of incinerator performance and environmental performance standards. The latter are proposed as alternatives to the land-based incinerator performance standards governing hydrogen chloride and particulate emissions.

Table 12 summarizes incinerator and environmental performance standards applicable to land-based and ocean incineration facilities. Each of these standards is defined and discussed below.

Combustion Efficiency (CE)

This measure of incinerator performance indicates the overall efficiency of the combustion process and can be monitored on a continuous basis. CE is represented by the relationship between the concentrations of carbon dioxide (CO_2) and carbon monoxide (CO) in the incinerator exhaust:

$$CE = \frac{[CO_2] - [CO]}{[CO_2]} \times 100$$

The CE standard is more stringent for ocean than for land-based incineration in two respects: the standard applies to all wastes, not only PCBs; and it is numerically higher (see table 12). The higher value is required because regulations promulgated under MPRSA must equal or exceed international regulations developed under the London Dumping Convention, which specifies a minimum CE of 99.95 ±0.05 percent for all wastes.

Destruction Efficiency (DE) or Destruction and Removal Efficiency (DRE)

These measures of incinerator performance indicate the extent to which particular compounds that were present in the waste feed are absent from emissions. DE and DRE must be calculated separately for each designated compound and, because the chemical analysis is complex and time-consuming, cannot be determined on a continuous basis. Consequently, the usefulness of DE and DRE in monitoring incinerator performance is limited.

DE and DRE are defined as follows:

$$DE \text{ or } DRE = \frac{[W_{in}] - [W_{out}]}{[W_{in}]} \times 100$$

Where $[W_{in}]$ is the concentration of a particular compound in the waste feed and $[W_{out}]$ is the concentration of the same compound in the emissions vented to the atmosphere.

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[2] Where there are no critera, the mixture could not exceed a marine aquatic life no-effect level or a toxicity threshold defined as 1 percent of an ambient marine water concentration shown to be acutely toxic to appropriate sensitive marine organisms (in a bioassay carried out in accordance with EPA-approved procedures). Marine water quality criteria have been developed for each of the 14 metals specified by EPA.

Table 12.—Performance Standards Applicable to Land-Based and Ocean Incineration

Performance standard	Land-based incineration	Ocean incineration
Combustion efficiency (CE)	99.9% for PCBs (TSCA)[a] No CE specified for any other wastes (RCRA)	99.95 ±0.05% for all wastes
Destruction efficiency (DE) or destruction and removal efficiency (DRE)	99.99% DRE except: 99.9999% DRE for PCBs, dioxins, dibenzofurans	99.99% DE except: 99.9999% DE for PCBs, dioxins, dibenzofurans
Hydrogen chloride (HCl) emissions	If >1.8 kg/hr, control to larger of either: a) ≤1.8 kg/hr or b) 1% of total HCl	After initial mixing, change in seawater alkalinity in release zone must be ≤10%
Particulate or metals emissions	≤180 mg/dry standard cubic meter, when corrected to 50% excess air	Metal emissions less than amount exceeding marine water quality criteria after mixing

[a] Incineration of PCBs requires a separate approval from the Assistant Administrator of the Office of Pesticides and Toxic Substances, in compliance with TSCA (40 CFR 761.70). EPA believes (and generally requires) that a CE >99.9% results in a DRE >99.9999%. (U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Summary and Conclusions," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).)

SOURCES: **Land-based incineration:** Incinerator Standards for Owners and Operators of Hazardous Waste Management Facilities (46 FR 7666-7683, Jan. 23, 1981) and subsequent amendments (47 FR 27516-27535, June 24, 1982). **Ocean incineration:** The proposed Ocean Incineration Regulation (50 FR 8222-8288, Feb. 28, 1985). **PCBs:** TSCA PCB incineration regulations (40 CFR 761.70).

The only difference between DE and DRE is that any removal of compounds accomplished by air pollution control equipment is included in the calculation of DRE, because DRE is measured *after* the devices have acted on emissions. Because air pollution control equipment is generally poor at removing organic constituents (2,13,15), however, DE and DRE are often functionally equivalent.

The waste destruction standard would be identical for land-based and ocean incineration (see table 12). Thus, despite their lack of scrubbers, incinerator vessels would have to achieve an emission rate for organic materials no higher than that allowed for land-based facilities.

Hydrogen Chloride (HCl) Emissions

Incineration of chlorinated wastes generates highly corrosive HCl gas. On land, if the rate of HCl *production* exceeds 1.8 kg/hr (4 lbs/hr), scrubbers must be employed to limit *emissions* to less than that amount or to remove 99 percent of the total, whichever results in the larger emission. EPA regards 99 percent removal as achievable using current technology.

For a land-based incinerator operating at median capacity (1,250 lbs/hr), any waste whose chlorine content was greater than 0.3 percent could be expected to exceed the HCl emission limitation of 4 lbs/hr and, hence, would require a scrubber. Once equipped with a scrubber that achieves 99 percent HCl removal, the same facility could incinerate waste with a chlorine content of up to about 30 percent without emitting more than 4 lbs/hr of HCl.

Incineration of waste with a chlorine content greater than 30 percent would be legal as long as 99 percent of the HCl were removed, but other practical constraints (e.g., corrosion, scrubber capacity, formation of chlorine gas) limit chlorine content to a maximum of about 35 percent.

For ocean incineration, EPA has proposed an environmental performance standard that would limit emissions to an amount that would result in no more than a 10 percent change in alkalinity of seawater in the release zone, measured 4 hours after release. EPA has calculated that this standard would be met even for incineration of pure carbon tetrachloride, whose chlorine content is over 90 percent, at the very high feed rate of 25 metric tons per hour. Given the significantly lower chlorine content and feed rates that would realistically be employed, it is highly unlikely that this environmental performance standard would ever be exceeded.

Particulate Emissions

The existing particulate standard for land-based incinerators is 180 mg per dry standard cubic meter, measured after correction to 50 percent excess air. The correction is designed to prevent operators from achieving the standard by simply diluting the emissions with excess air rather than actually controlling particulates.

The rationale for controlling particulates is twofold: First, particulate matter itself can be hazardous, because it can include toxic metals, which are not destroyed during incineration; and second, other hazardous constituents, including unburned or partially burned organic compounds, can adsorb to particulate matter. Although the chemical analysis used to calculate DRE accounts for unburned parent compounds bound to particulate matter, the DRE standard does not in any way measure or limit *partial* combustion products (e.g., PICs) or metals.

The particulate standard applicable to land-based hazardous waste incinerators is identical to that required of municipal incinerators under the Clean Air Act's New Source Performance Standards (12).

For ocean incineration, EPA has proposed an environmental performance standard for metals instead of establishing a direct particulate emissions standard. The proposed environmental standard would limit incinerator emissions so that:

> . . . the effect of the emissions would not unreasonably degrade or endanger human health, welfare, or amenities, or the marine environment, ecological systems, or economic potentialities or recreational or commercial shipping or boating or recreational use of beaches or shorelines (Section 234.48(b) of EPA's proposed Ocean Incineration Regulation, 50 FR 8266, Feb. 28, 1985).

EPA has interpreted this rather vague language to mean that concentrations of particular constituents in wastes to be incinerated would be limited to amounts that would prevent the resulting mixture of incinerator emissions and seawater from exceeding marine water quality criteria.[3]

This standard would theoretically apply to any substance present in incinerator emissions. In practice, however, criteria and toxicity thresholds have been developed for few chemicals, and this standard would primarily be used to limit metal concentrations allowed in wastes incinerated at sea. Because liquid wastes suitable for ocean incineration typically generate low levels of particulates, EPA considers the proposed limitations to be a justifiable alternative to requiring particulate control devices on incinerator vessels.

Although the environmental performance standard appears to address harmful metal emissions, whether it can adequately control emissions of PICs associated with particulates is controversial. EPA argues that at the high temperatures employed in ocean incineration, essentially all organic compounds would be in a volatilized state and not adsorbed to particulate matter. Thus, particulate removal equipment would not help to reduce PIC emissions (1). However, some observers argue that certain organic compounds, including PCBs, dioxins, and dibenzofurans, can to some extent associate with particulate matter even at high temperatures. In addition, these observers maintain, other mechanisms exist for including organic matter in the particulate fraction of incinerator emissions (9,10).

Further research will probably be essential for resolving this controversy. EPA's proposed research strategy for ocean incineration would include tests designed to address the issue (14).

Operating Conditions

Operating permits for both land-based and ocean incineration facilities specify sets of operating conditions that were demonstrated in trial burns to be capable of achieving the performance standards discussed above. A set of conditions is determined for each waste feed expected to be burned. Periodic waste analyses must be performed to demonstrate that wastes actually incinerated are within the range for which a permit is written.

Land-Based Incineration

For land-based incinerators, each set of operating conditions includes limits on at least the following parameters:

- the carbon monoxide level in the exhaust stack gas (indicates combustion efficiency, completeness, or upset);
- waste feed rate;
- combustion zone temperature, with location of sensor specified;
- appropriate indicator of combustion gas ve-

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[3] See footnote 2.

- locity (indicator of residence time in the combustion zone); and
- air pollution control device operating conditions.

In addition to these waste feed-specific conditions, several operating requirements are uniformly applied to all land-based incinerators:

- during startup and shutdown, hazardous wastes cannot be fed to incinerators unless they are operating under specified conditions;
- combustion zones must be completely sealed and maintained under negative pressure in order to control fugitive emissions; and
- automatic shutoff systems must be employed to halt waste feed when operating conditions deviate from specified limits.

Incineration of PCBs requires separate approval from the Assistant Administrator of the Office of Pesticides and Toxic Substances, in compliance with the Toxic Substances Control Act (TSCA). Additional operating conditions are specified:

- 1,200 ±100° C, 2.0 second residence time, 3 percent excess oxygen; or
- 1,600 ±100° C, 1.5 second residence time, 2 percent excess oxygen.

Photo credit: SCA Chemical Services/Air Pollution Control Association

The computerized control room at a land-based incineration facility.

Other operating conditions are allowed if they can be demonstrated to achieve the required DRE.

Ocean Incineration

The proposed Ocean Incineration Regulation would also use a trial burn to determine appropriate sets of operating conditions and waste feeds. For certain wastes specified in London Dumping Convention (LDC) regulations, if a contracting party to the Convention "has doubts as to the thermal destructability of the wastes," then a separate test burn would have to be conducted to ensure that all standards could be met. Because of the anticipated difficulty in achieving their complete thermal destruction, the following wastes would receive special attention:

- polychlorinated biphenyls (PCBs);
- polychlorinated terphenyls (PCTs);
- tetrachlorodibenzo-p-dioxin (TCDD);
- benzene hexachloride (BHC); and
- dichlorodiphenyl trichloroethane (DDT).

EPA considers available data sufficient to document the ability of incinerators to destroy PCBs, BHC, and DDT to the level specified by the LDC (50 FR 8228, Feb. 28, 1985). Because a 99.9999 percent standard applies to PCBs and TCDD and data are lacking for PCTs, however, test burns would be mandated for these three substances.

Operating permits for incineration vessels would have to specify allowable limits for at least two operating conditions:

- carbon monoxide concentration in combustion gases, and
- waste feed rate to the incinerator.

The proposed regulation specifically sets limits on the following additional operating parameters:

- minimum flame temperature of 1,250° C;
- minimum wall temperature of 1,100° C;
- minimum 3 percent oxygen concentration in the combustion gases; and
- residence time in the combustion zone of at least 1.0 second.

For all of these except residence time, alternate values could be substituted in the operating permit, if other conditions were demonstrated in a trial burn to be capable of achieving the performance standards.

The proposed regulation also specifies a set of general operating requirements that would apply to all vessels at all times:

- no black smoke or flame may extend above the stack plane;
- between startup and shutdown, hazardous waste could not be fed to incinerators unless they were operating under specified conditions;
- automatic shutoff systems would have to be employed to halt waste feed when operating conditions deviated from specified limits; and
- all residues would have to be incinerated at sea or transported back to land for proper disposal.

This comparison of requirements for operating conditions shows that the proposed Ocean Incineration Regulation generally tends to specify values for more operating parameters and leaves less to the judgment of individual permit writers than do the regulations governing land-based facilities.

Air Pollution Control Technology

Effect of Scrubbers on Emissions From Hazardous Waste Incinerators

Currently available air pollution control equipment generally controls emissions of particulates and acidic gases very effectively but removes organic compounds (parent compounds and PICs), certain metals (e.g., mercury), and nitrogen oxides very poorly.

An EPA study of land-based incinerators found that, for various wastestreams, scrubbers had little or no detectable effect on the levels of unburned waste (parent compounds) present in emissions (13). Based on these and other data, air pollution control devices cannot be expected to remove residual parent compounds or PICs from incinerator exhausts or to provide an extra margin of safety in the event of operation upset (2,15).

Although scrubbers effectively control emissions of particulate metal oxides and gaseous sulfur oxides, controlling volatilized metals and nitrogen oxides is exceedingly difficult, particularly for hazardous waste incinerators. This is because: 1) wet scrubbers are ineffective at removing them; and 2) other control measures often entail decreasing the operating temperature, which must be maintained to ensure complete combustion of hazardous wastes.

Land-Based Incineration

Scrubbers are required for land-based incinerators that burn wastes whose chlorine or particulate content would otherwise cause emissions standards to be exceeded. EPA estimates that about 45 percent of land-based incinerators currently operating, including the large commercial incinerators, carry some sort of air pollution control equipment (8). Scrubber technology, especially for removing particulates, is well-developed but expensive.

Land-based incinerators regulated under RCRA (or TSCA for PCBs) are also subject to controls on scrubber waste disposal. Scrubber operation generates very large amounts of scrubber water (see ch. 8), which is itself classified as a hazardous waste. Several methods, all subject to RCRA regulation, are used for treating this residual. The methods include impoundment, deepwell injection, treatment, and landfilling. Treatment generates two products: a sludge, which is generally disposed of in a hazardous waste landfill; and an effluent, which can be legally discharged to surface waters or into sewer systems if the effluent meets the requirements of the Clean Water Act.

Ocean Incineration

Proposed domestic regulations, as well as existing international regulations, do not require the use of any air pollution control equipment on incineration vessels. Separate rationales are offered for the two major categories of incinerator emissions: acid gases and particulates. EPA argues that acid gases emitted from the stack would be effectively neutralized on contact with seawater because of its natural buffering capacity. As an additional control, the proposed Ocean Incineration Regulation would impose an environmental performance standard for acid gas emissions (see previous section).

EPA also considers that burning only liquid wastes at sea would generate very low levels of particulates and that controls over metal content in waste would further limit harmful metal emissions. Limitations on metal content of wastes burned at sea would be based on EPA's interpretation of the London Dumping Convention's guidelines with reference to water quality criteria.

Two companies, SeaBurn, Inc., and Environmental Oceanic Services, Inc., have proposed plans for incineration vessels that would be equipped with seawater scrubbers, but their purpose would only be to dilute the plume and direct it more quickly into the ocean. The scrubbers, therefore, would not generate any scrubber residuals (see ch. 6).

Sampling and Monitoring Requirements and Procedures

Three levels of monitoring are generally discussed with regard to incineration: monitoring of trial burns; routine monitoring of emissions and incinerator operating conditions; and ambient monitoring of surrounding air, water, and biota. Each of these is discussed below for land-based and ocean incineration.

Land-Based Incineration

Sampling and analysis procedures for incinerator emissions are specified in Federal regulations and EPA manuals. For the trial burn, actual locations for sampling and monitoring devices are indicated, and data collected are used to determine performance of the incinerator by providing for the following:

- quantitative analysis of waste feed, stack emissions, scrubber water, and ash and other residues;
- computation of DE or DRE;
- acid gas removal efficiency;
- quantification of particulate emissions;
- measurement of average, maximum, and minimum combustion temperature;
- continuous measurement of carbon monoxide concentration in the stack gases; and
- identification of the sources of fugitive emissions.[4]

Operating permits for routine incineration specify waste analysis and monitoring requirements. A waste analysis plan is required and must provide for periodic verification of the chemical and physical composition limits specified in the permit. RCRA requires that temperature, carbon monoxide, waste feed rate, and combustion gas velocity be continuously monitored during operational burning and that an automatic waste feed shutoff system be continuously operated, as well. Waste feed shutoff is triggered by deviation from permit limits in any of several operating parameters, as determined by the continuous monitoring devices. Sampling and analysis of waste feed or emissions must be conducted on request by the EPA Regional Administrator. All sampling and monitoring data must be recorded.

RCRA does not require ambient monitoring for land-based incinerators, although some individual States might have such requirements under the Clean Air Act. EPA offers three reasons for not mandating ambient monitoring: the Agency believes that if stack emissions are within regulatory limits, no adverse effects will occur; accurate and reliable ambient monitoring would not be feasible because concentrations are extremely low; and other industrial activities contribute similar or identical emissions, which would impede attempts to assign sources to emissions or their effects.

Ocean Incineration

For trial burns, proposed Federal regulations specify sampling and analysis procedures for parent compounds. Routine operations would require continuous monitoring, which would have to be recorded in sealed tamper-resistant devices, of the following parameters:

- incinerator wall and flame temperatures;
- oxygen, carbon dioxide, and carbon monoxide concentrations in the combustion gases;
- waste and auxiliary fuel feed rates to the incinerator;
- air flow to the combustion chamber;
- status of the flame (to monitor continuous combustion); and
- amount of waste incinerated.

An automatic waste feed shutoff system would have to be operated continuously and be triggered by deviations from specified limits for: minimum wall temperature and minimum oxygen and maximum carbon monoxide in combustion gases; flame-outs; or failure in continuous monitoring devices.

Tests of ballast waters, tank washings, pumproom bilge waters, and wash waters from decontamination operations would have to be performed and recorded to ensure compliance with permit requirements.

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[4] Fugitive emissions are small, sporadic losses of waste from sources like leaking valves, vents, and seals.

Vessel operators would be required to monitor ambient air, water, and biota, using approved methods under the direction of EPA. The monitoring would be conducted periodically or at the request of the permit program managers. Costs would be borne by individual vessel operators.

EPA would have authority to review and approve the qualifications of all personnel involved in collecting and analyzing samples for monitoring emissions and the ambient environment.

As was the case for operational requirements, proposed sampling and monitoring requirements are generally more detailed and stringent for ocean incineration than for land-based incineration.

Additional Provisions Not Required of Land-Based Incineration

The proposed Ocean Incineration Regulation contains several requirements that do not have counterparts in RCRA regulations governing land-based incineration. These requirements include the following:

- all data from waste analyses and monitoring would have to be submitted to EPA;
- operators would have to meet additional requirements regarding the collection and reporting of monitoring data. The requirements would specify, for example, the frequency of recording and the use of tamper-resistant devices;
- a full-time EPA shiprider would be required on each voyage, and the U.S. Coast Guard could require an additional shiprider;
- facilities and records would be inspected yearly by the U.S. Coast Guard and on request by EPA;
- permit applicants would have to assess the effects of their activities on endangered or threatened species, and EPA would have to conduct and periodically update its own endangered species assessment, under the authority of the Endangered Species Act;
- the activity would have to be consistent with the Coastal Zone Management Act; and
- operators must demonstrate the need for ocean incineration (see ch. 2).

Although many of these requirements address concerns arising from the fact that ocean incineration takes place far from land, together they reinforce the conclusion that the proposed Ocean Incineration Regulation would be considerably more explicit and stringent than the corresponding regulations for land-based incineration.

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Chapter 8

Environmental Releases From Ocean Incineration

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Chapter 8

Environmental Releases From Ocean Incineration

Incineration is a technology primarily intended to *destroy* hazardous wastes. However, as with any hazardous waste technology, each phase of operation has at least the potential to release waste or waste products into the environment.

A full quantitative analysis of the magnitude and probability of releases from incineration is not possible, primarily because insufficient data exist on which to base such an analysis. This chapter first comments on these data limitations and then describes the nature of releases associated with ocean incineration. It then presents and analyzes available data on the probability of such releases occurring, and compares these risks with those from similar activities (i.e., land-based incineration, marine transportation of hazardous materials, and additional sources of marine pollution).

The chapter ends with a summary and comparative discussion of the total releases expected from land-based and ocean incineration. This summary ties together the large amount of information presented in the chapter and provides an overview that may suffice for readers who do not wish to explore the subject in detail.

DATA LIMITATIONS

Any discussion of risks arising from land-based and ocean incineration is greatly hampered by a lack of data on many key aspects. This chapter often refers to such data gaps, particularly those cited by EPA's Science Advisory Board. Significantly, our understanding of risks from *both* land-based and ocean incineration is comparably constrained by this lack of needed data. Indeed, many of these data gaps apply to many or all other hazardous waste management technologies as well.

Without sufficient data, a very large degree of uncertainty taints all of the risk calculations and some of the overall conclusions, as well. At the same time, given the truism that no method for managing hazardous wastes is risk-free, the most important information is that which provides for a *comparative* assessment of risks. Although this task is difficult and by no means free of uncertainties, an evaluation of relative risk can be developed now and subsequently refined as the information base improves.

For ocean incineration, data with which to assess the potential for both accidental and routine releases are particularly scant, in part because of the relative lack of experience with this technology (at least in the United States). This necessitates a reliance on indirect historical data for such releases (i.e., data collected for related activities such as hazardous materials transportation[1]). In addition, the lack of experience has provided only limited opportunities to collect data on routine releases occurring under a wide range of operating conditions.

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[1] OTA has examined the risks involved in transportation of hazardous materials, including waste (19).

TYPES OF ENVIRONMENTAL RELEASES

Environmental release of waste from incineration operations can occur as a result of accidents, such as vessel or truck collisions, leaking tanks, or upsets in incinerator operation. Releases can also result from normal or routine operations, when, for example, small fractions of unburned waste are emitted from incinerator stacks or waste or residual ashes are handled. A full analysis of the environmental effects of land-based and ocean incineration will ultimately require that both kinds of releases be characterized and quantified.

Several important distinctions can be drawn between these two types of events.

Accidental releases are not predictable with respect to time or place, although historical data can be used to develop estimates of their probability of occurrence. For events that occur relatively often, as do, for example, vehicle accidents, historical data can provide accurate risk estimates. However, for rare events such as ship groundings, or for events arising from unique aspects of a new technology, historical data either are nonexistent or produce much less reliable estimates.

Both the frequency and the magnitude of accidental releases are subject to influence by regulatory and technical factors. For example, use of containerized systems for transporting wastes can decrease the quantity of wastes released in the event of accidents, and restrictions on vessel transit during storm conditions should reduce the likelihood of accidents.

Routine releases are easier to predict and quantify. Although the magnitude of routine releases can be minimized through technological design and careful practice, some release is inevitable from essentially any system.

Routine releases resulting from incineration can involve either the waste itself or products generated as a result of the incineration. Accidental releases virtually always involve loss of the original waste itself.

This section describes the various types of environmental releases and, wherever appropriate, draws distinctions between land and ocean basing. The types of releases considered include the following: accidental releases from spills and incinerator upsets; and routine releases from fugitive emissions, normal stack emissions, and air pollution control device effluents.

Available data are discussed from two perspectives: First, the additional activities and risks specifically associated with ocean incineration are highlighted; and second, these risks are compared to risks associated with related activities, to provide a broad context in which to view ocean incineration.

Marine Spills[2]

Typically, handling and transport of hazardous waste to be incinerated involves many similar or identical steps for both land-based and ocean incineration. Figure 9 presents a schematic representation of such steps for land-based and ocean incineration. The potential for a spill to occur must be evaluated at each of these steps. For ocean incineration, an extra transfer and transport step is required to bring wastes to dockside, load them onto the vessel, and transport them to the incineration site. This factor tends to increase the risk of accidental release of wastes. (As discussed in ch. 6, implementation of the containership concept, in which wastes would be transferred directly from source to vessel in sealed containers, might substantially reduce this risk during handling on land and during vessel loading; increased handling of containers on board could increase the risk of a spill during the voyage.)

Table 13 summarizes steps in the waste flow where accidents can occur, and indicates the cause and type of release in each case.

With respect to additional transportation and handling risks applicable to ocean incineration, EPA estimated the probability of release for a ship with characteristics similar to the *Vulcanus II*, operating in two locations: 1) out of Mobile Bay in Alabama and incinerating at the designated Gulf of Mexico Incineration Site (app. C in ref. 22); and 2) out of Philadelphia and Delaware Bay and incinerating at the proposed North Atlantic Incineration Site (8). These analyses were based on consideration of historical safety and engineering data for the maritime bulk chemical industry. Specifically, bulk chemical transport data for tank ships of comparable size operating worldwide between 1969 and 1982 formed the basis of the analysis. The data were adjusted to account for the following special circumstances and the somewhat stricter design and operational requirements applicable to incinerator ships:

- relative ease of maneuvering and use of sophisticated navigational equipment;

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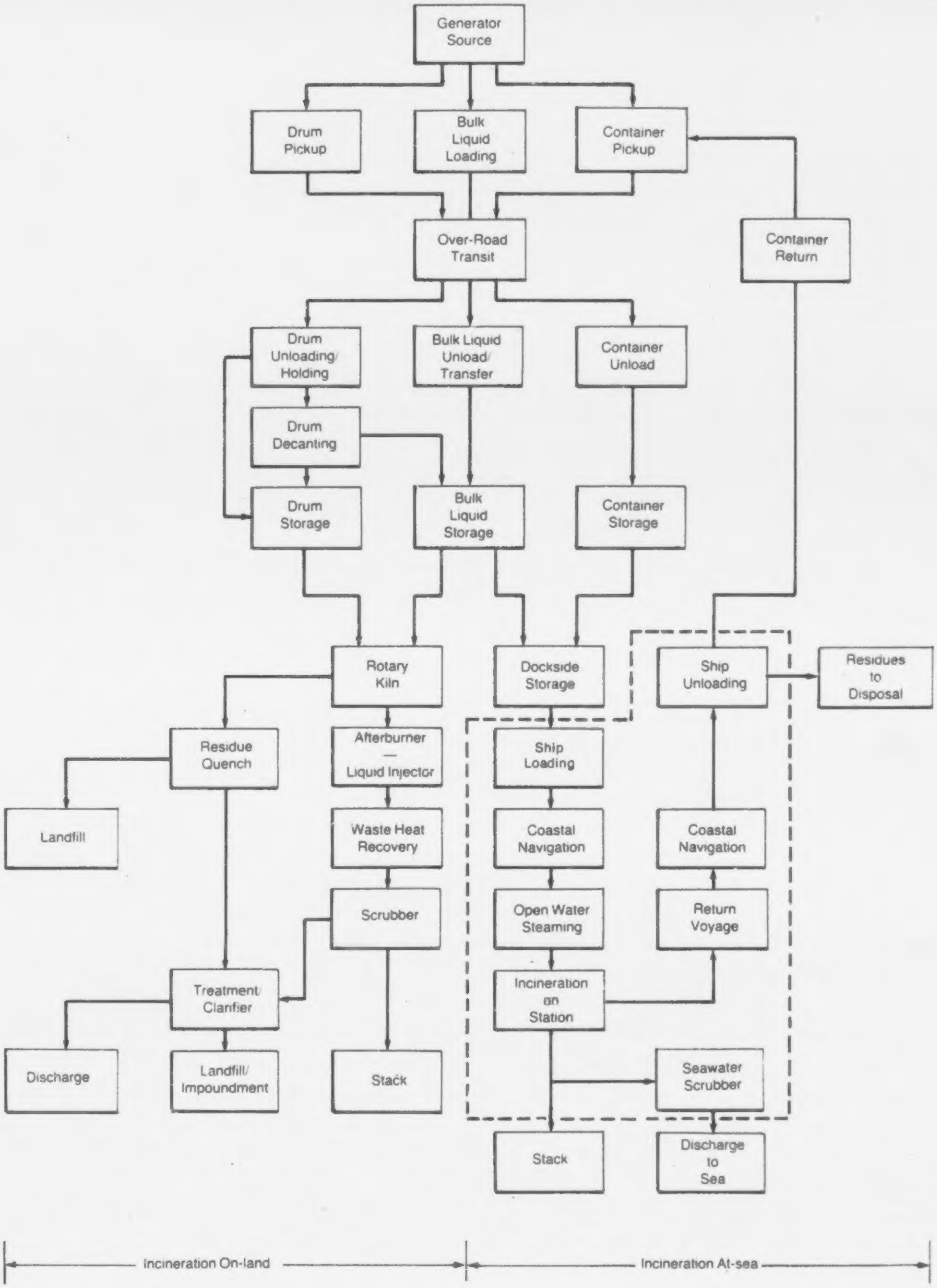
[2] In this discussion, the term *spill* refers to a release caused by the breaching of a cargo tank. Other releases caused by leaking valves, etc., are considered later in the section on fugitive emissions.

Figure 9.— Step-by-Step Flowchart for Land-Based and Ocean Incineration


Generator Source
Drum Pickup
Bulk Liquid Loading
Container Pickup
Over-Road Transit
Container Return
Drum Unloading/ Holding
Bulk Liquid Unload/ Transfer
Container Unload
Drum Decanting
Drum Storage
Bulk Liquid Storage
Container Storage
Rotary Kiln
Dockside Storage
Ship Unloading
Residues to Disposal
Residue Quench
Afterburner — Liquid Injector
Ship Loading
Landfill
Waste Heat Recovery
Coastal Navigation
Coastal Navigation
Scrubber
Open Water Steaming
Return Voyage
Treatment/ Clarifier
Incineration on Station
Discharge
Landfill/ Impoundment
Stack
Seawater Scrubber
Stack
Discharge to Sea
Incineration On-land
Incineration At-sea

Note: Area within dotted line represents one cycle of the ship

SOURCE: Arthur D. Little, Inc., *Overview of Ocean Incineration*, prepared by J.R. Ehrenfeld, D. Shooter, F. Ianazzi, and A. Glazer for the Office of Technology Assessment (Cambridge, MA: May 1986).

Table 13.—Accidental Releases From Land-Based and Ocean Incineration

Activity	Cause of release	Type of release	Relevant mode
Waste pickup/loading/unloading:			
Drums	Mishandling	Spill on land	Land/ocean, bulk
Bulk liquids	Overfilling, line break	Spill on land	Land/ocean, bulk
Containers	Mishandling	Spill on land	Land/ocean, containerized
Road or rail transit	Vehicle accident, tank or valve leak	Spill on land Fire	Land/ocean, bulk/containerized
Storage:			
At dockside	Tank or container failure	Spill on land	Ocean
At incinerator	Tank or container failure	Spill on land	Land
Vessel loading	Overfilling, line break	Spill on land, water, or ship	Ocean, bulk
Vessel transit	Collision or grounding	Spill to water or on ship	Ocean, bulk
Incineration	Upset or malfunction	Increased emissions	Land/ocean, bulk/containerized
Bulk liquids or containers	Mishandling	Spill	

SOURCE: Arthur D. Little, Inc., *Overview of Ocean Incineration*, prepared by J.R. Ehrenfeld, D. Shooter, F. Ianazzi, and A. Glazer, contract report prepared for the U.S. Congress, Office of Technology Assessment (Washington, DC: May 1986).

- segregated ballast design and dedicated ballast and cargo tanks;
- double-hull and double-bottom design;
- dedicated port facility;
- specially trained crew;
- weather restrictions during transit;
- U.S. Coast Guard transit requirements (e.g., moving safety zone); and
- routes to be used.

The probability of an accident occurring during various segments of the transit was separately assessed for four locations: the pier or harbor, Mobile or Delaware Bay, the coastal zone, and the burn site. Four types of accidents were separately addressed as well: collisions (ship/ship); rammings (ship/nonship); groundings; and nonimpact events (e.g., explosions, fires, structural failures, capsizing).[3] In addition, accident data were adjusted to account for the fact that not all accidents result in actual release of waste.

The resulting estimates are of two sorts: first, estimates of the probability of a spill (i.e., spill rate) of any size occurring at a given location or from a given type of accident; and second, a probability distribution that predicts the frequency of spills of various sizes.

Estimation of Spill Rates

For a *Vulcanus II*-type ship, EPA's estimated spill rates for the Gulf of Mexico and for Delaware Bay are presented in figure 10. The total spill rates are the sum of those for the four locations or the four types of accidents. These data suggest that about half of all spills in both locations can be expected to occur at dockside or in the harbor or bay. Nonimpact casualties (e.g., explosions, fires, structural failures, capsizing) are predicted to account for almost half of all spills in the Gulf of Mexico, but less than a third of those in Delaware Bay. Spills due to groundings are over four times more likely in Delaware Bay than in the Gulf, largely because of differences in bottom conditions. Based on historical accident rates, a major fraction of spills in the pier/harbor area are expected to take place while the vessel is moored, rather than during transit.

Based on these data, EPA predicts that the overall spill rate for all accident types and locations would be 6 per 100,000 voyages for the Gulf of Mexico and 9 per 100,000 voyages for Delaware Bay. As can be seen from figure 10, most of the difference in these two estimates is because of the higher probability of groundings in the Delaware Bay, due to harder bottom conditions.

These estimated spill rates for the *Vulcanus II* are seven- to ten-fold lower than the historical spill

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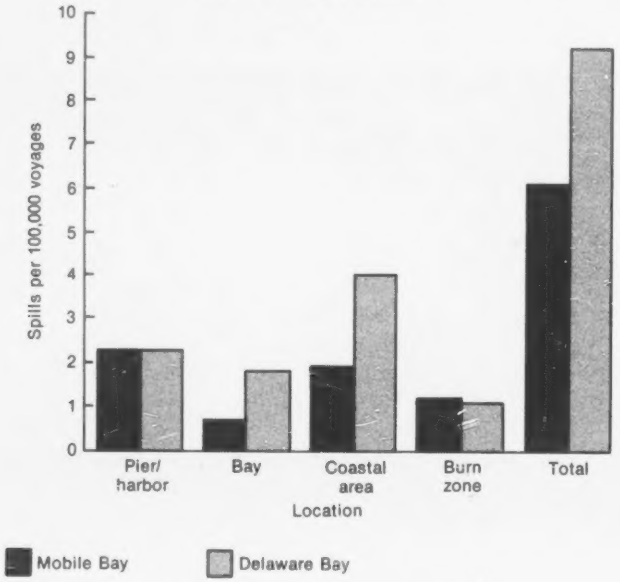
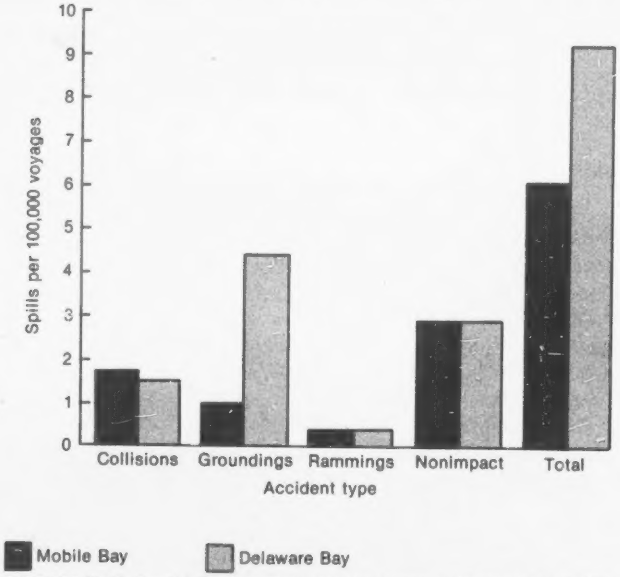
[3] Adjustments of the data were made where appropriate to account for conditions specific to a location and an accident type. For example, probabilities for vessel groundings in Delaware Bay were adjusted upward based on the higher rate of groundings in this region relative to that experienced worldwide; probabilities for groundings in the Gulf of Mexico were adjusted downward to account for soft bottom conditions. No adjustments of data for nonimpact accidents were made, due to lack of sufficient information.

Figure 10.—Spill Rates for the *Vulcanus II* in Mobile and Delaware Bays

A. Spill Rates by Location



B. Spill Rates by Accident Type



SOURCES: **Mobile Bay:** U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Based Incineration," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: March 1985); **Delaware Bay:** Engineering Computer Optecnomics, Inc., "Analysis of the Risk of a Spill During a Single Voyage of the *Vulcanus II* From the Port of Philadelphia to the Incineration Site in the Atlantic Ocean," prepared for the U.S. Environmental Protection Agency (Annapolis, MD: Apr. 30, 1986).

rate for all tank ships of comparable size operating worldwide between 1969 and 1982 (61 per 100,000 voyages). Such a result is expected because of the adjustments made to account for the special safety features of incineration vessels and their operation.

Using EPA's assumption of an average of 14 voyages per ship per year, these spill rates indicate that one accident could be expected to occur every 800 years (Delaware Bay) to 1,200 years (Gulf of Mexico). These estimates are *per ship*; thus, if three ships were in operation, one spill would be expected every 270 to 400 years on average.

EPA's spill rate estimates are subject to a number of limitations. For example, spill rates only represent a *Vulcanus II*-type vessel operating in specific regions, and cannot be expected to apply to other vessel designs or locations. In addition, spills of hazardous material go unreported to a significant degree. No upward adjustment was made to account for the number of unreported accidents and spills. Such an adjustment would affect the *absolute* probability of a spill for the *Vulcanus II,* but not its safety *relative* to that of all tank ships operating worldwide.[4]

EPA's spill rate estimates are highly sensitive to the magnitude, reliability, and appropriateness of adjustments made to historical spill data. For example, if it is assumed that only a quarter of all marine spills are reported, then the actual spill frequency would be increased by a factor of 4. The resulting spill rates would now be 1 per 200 to 300 years (again *per ship*). If three ships were operating, a spill could be expected every 67 to 100 years; if a larger fleet of 30 ships were employed, a spill could be expected every 7 to 10 years.

Conversely, the downward adjustments made to historical spill data might be too conservative. For example, nonimpact accidents may well be affected by design and operational features that are employed (e.g., double-hull construction; sophisticated firefighting equipment). These factors were excluded from EPA's analysis due to a lack of quantitative information. Their consideration would result in actual spill rates that would be even smaller than EPA has estimated.

The factors listed above represent only some of the many inherent sources of uncertainty that affect the reliability of spill rate estimates. Even if only small uncertainties accompanied each of the individual factors that influenced the calculation of a spill rate, the combined uncertainties could lead to a highly questionable result. For this reason, the *absolute* magnitude of such risk estimates must be used with great caution.

Comparing the *relative* risks for activities that are subject to the same or similar uncertainties, however, can still be informative. Thus, a major conclusion that is clearly supported by EPA's spill rate analysis is that **the operation of incineration vessels should result in a significantly lower per-ship rate of spills than the rate for tank ships in general**.

Estimation of Spill Size

EPA rejected use of direct historical data on spill size for tank ships, because such data are skewed toward conventional single-hull tankers whose average *tank* size is comparable to the *entire cargo* of the *Vulcanus II*. Instead, historical data on the extent of damage caused by accidents were used to estimate the probability of occurrence of each of the following categories of events leading to cargo loss:

- involvement of a single cargo tank—80 percent of spill events,
- involvement of two adjacent tanks—15 percent of spill events, and
- involvement of three or more tanks—5 percent of spill events.

In each case, it was assumed that the entire contents of a tank involved in an accident were lost. Because the *Vulcanus II* is designed to remain afloat even after the loss of two of its tanks, cargo losses from events involving damage to one or two tanks would be limited to their corresponding volume (about 100,000 and 200,000 gallons, respectively). However, for events involving three or more tanks, loss of the entire cargo (about 800,000 gallons) was assumed. These assumptions are quite conservative because of the unlikelihood that all the con-

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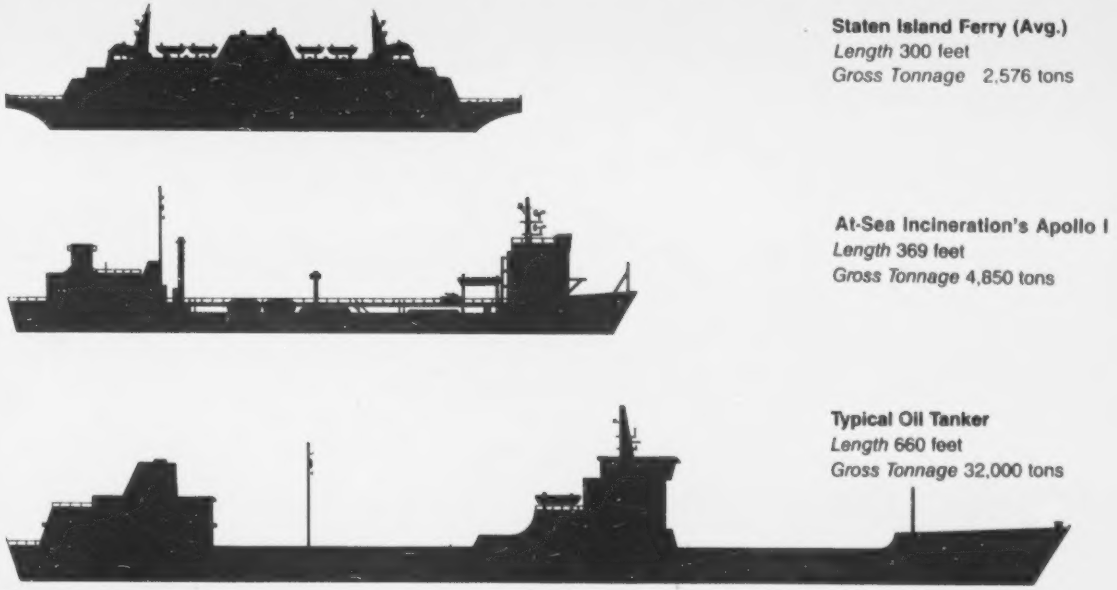
[4] A number of other criticisms of the EPA analysis have been raised (6), based primarily on U.S. Coast Guard data on polluting incidents in and around U.S. waters (20). However, most of these data are not relevant to evaluating the risk of a spill from an incinerator vessel, in that: 1) the incidents did not result in any release of waste; 2) the incidents involved sources other than vessels; or 3) the vessels involved were of significantly less safe design (e.g., river barges).

Figure 11.—Comparative Size Scale of an Incineration Vessel (the *Apollo I*) and Other Typical Commercial Ships



SOURCE: At-Sea Incineration, Inc.

tents of a tank would be lost in all accidents. These "worst-case" data suggest that an average spill from an incineration vessel would result in the release of 19 percent of the total cargo, which would correspond to about 150,000 gallons in the case of the *Vulcanus II*.

Unfortunately, essentially no data are available for vessels of comparable size and possessing the design and operational features of incineration vessels. Moreover, because historical data collected over only a few years may by chance include or exclude the very rare event that generates a very large spill, their reliability is highly questionable. These and the other limitations discussed above clearly illustrate the problems associated with using historical data to estimate the average magnitude of a low-probability, high-consequence event such as a marine spill.

Whatever its absolute magnitude or uncertainty, **the average expected spill size from an incineration vessel can logically be assumed to be significantly smaller than that resulting from a typical tanker accident, where both tank and total cargo size tend to be much larger** (see fig. 11).

Estimates of spill rate and size are certain to vary between vessels, port locations, and burn sites. Thus, an analysis based on any one operation is of limited applicability to others, whereas a generic analysis tends to obscure the potential for significant variation. This fact underscores the need for comparing various vessel designs and operation plans as an integral part of assessing the safety of ocean incineration (see ch. 6).

Comparison of Releases From Transportation on Land and At Sea

EPA estimated the magnitude of releases that would be expected to occur as a result of accidental spills during land and ocean transportation (21,22). Based on this comparison, EPA suggested that the ocean transportation phase would contribute about 20 percent of releases of waste caused by spills. Releases caused by spills during land transportation are estimated to be more than three times higher than releases caused by spills during ocean transportation. Releases caused by spills during transfer and storage operations would be slightly lower than releases caused by spills during ocean transportation. Because spill releases from land transportation, transfer, and storage are estimated to be identical for land-based and ocean incineration, EPA suggested that the total expected release due to spills for ocean incineration would be about 20 percent higher than that for land-based incineration.

Even if accurate, however, such estimates do not adequately reflect the relative environmental consequences of releases. To do so would require consideration of such factors as the ease of cleaning up spills, the transport and fate of spilled material, the nature of exposure to organisms and humans, and the actual health effects of the substances present in the waste. Compared to estimation of spill rate and size, far more uncertainty and absence of data accompany the estimation of these additional factors, which are considered in chapter 9.

Comparison of Marine Transportation of Hazardous Waste and Nonwaste Materials

Available data indicate that, with respect to number of transits, quantities and types of material carried, and expected releases, ocean incineration entails a very small incremental increase in risk over that routinely borne in the marine transport of hazardous materials. **Even if a fleet of 30 vessels were employed, marine transport of hazardous materials would increase by about one-tenth of 1 percent; quantities of material spilled in the marine environment would increase by an even smaller fraction.**

A discussion of the risks of accidental releases of wastes while at sea or dockside should consider both the types and quantities of hazardous *nonwaste* materials (e.g., petroleum products, raw chemical feedstocks) that are handled and transported by similar means and routes on a routine basis.

Types of Material Carried.—Critics of ocean incineration argue that transport of hazardous waste poses a greater risk than transport of hazardous nonwaste materials for two reasons: first, that waste materials are more toxic or concentrated; and second, that incineration vessels would carry complex mixtures of different substances, whereas tank ships carry pure substances, which are easier to clean up if spilled.

Typical liquid cargoes carried by tank ships include crude oil, petroleum products, petrochemicals, liquefied gases, and nonpetroleum-based chemicals. Thus all of the major categories of ocean-incinerable wastes are represented among materials routinely transported in raw form. In addition, many tank ships are designed and authorized to carry numerous substances in various combinations, for example, petroleum products and nonpetroleum-based chemicals. These materials, however, are segregated in separate tanks, reducing the likelihood that a mixture of substances would be released in a tank ship spill.

With respect to toxicity and concentration, the majority of waste suitable for incineration at sea is derived from industrial processes that use a wide variety of chemicals in pure form. The composition of waste generated by a given industrial process, therefore, tends to reflect rather closely the composition of the feedstocks initially used.

However, industrial processes can alter the composition of subsequent waste products in at least three respects. First, contaminants can be introduced; for example, solvents used for cleaning and degreasing may contain dirt, grease and oil, and metals not originally present in the feedstocks. Second, water content can be increased, diluting the original material. Third, different substances can indeed become mixed in the process that generates the waste.

Thus, contamination or mixing can render wastes resulting from industrial processes more complex than the nonwaste materials from which they were derived; at the same time, the concentrations of particular toxic constituents may well be less than those of the raw materials. Because environmental toxicity is a function of *both* concentration and composition, any generalization about relative toxicities of wastes and raw materials is impossible; rather, analysis on a case-by-case basis is required.

Much public attention has focused on the transport of PCBs, which are no longer routinely produced or transported for industrial or other commercial purposes. Although PCBs are a small fraction of ocean-incinerable wastes, they are among the most environmentally persistent of all toxic materials transported at sea, and have considerable potential to be accumulated by exposed organisms and introduced into the food chain. For this reason, special regulatory attention is warranted for PCBs. (See box B in ch. 3.)

Quantities of Material Carried.—EPA has estimated that the amount of hazardous waste that would be transported by the six existing or planned incinerator ships would be 0.03 percent of the total volume of hazardous substances handled by U.S. ports in 1983 (50 FR 8226, Feb. 28, 1985). This calculation was based on U.S. Army Corps of Engineers data reporting a total of 1.38 billion metric tons[5] of hazardous materials passing through U.S. ports in 1983.

Table 14 provides a summary of U.S. Army Corps of Engineers data on the annual tonnages of hazardous materials and petroleum passing through various U.S. ports in 1984. These amounts are compared to the quantities that would be carried by 1 or 30 incineration vessels similar in size to the *Vulcanus* ships or the significantly larger *Apollo* ships.

Gulf of Mexico and Mobile Bay.—EPA has examined data on shipments of petroleum and hazardous substances in Mobile Bay and the Gulf of Mexico. The data distinguish between crude petroleum, petroleum products, and hazardous chemicals. Table 15 presents data for shipments in and out of Mobile Bay between the years 1977 and 1981. Table 16 presents similar data for the Gulf of Mexico in 1983 and indicates the total number of shipments made.

The data in tables 15 and 16 provide the basis for the following conclusions:

- Each incineration vessel with an annual capacity of 65,000 metric tons operating full time out of Mobile Bay would increase total carriage there by the following amounts:
  —for all commodities listed: 0.8 percent, and
  —excluding crude petroleum: 1.6 percent.
- Each such vessel would increase carriage in the Gulf of Mexico by the following amounts:
  —for all commodities listed: 0.01 percent, and
  —excluding petroleum: 0.02 percent.
- Assuming that each such vessel made 14 transits annually, the number of *hazardous material shipments* in the Gulf of Mexico would

Table 14.—Annual Tonnages of Hazardous Materials and Crude Petroleum Passing Through Various U.S. Ports in 1984

	Quantity Transported in 1984 (millions of metric tons)			
Location	Hazardous materials[a]	Crude petroleum	Total	Quantity normalized to one *Vulcanus* vessel
Total for all U.S. ports (1983)[b]	—	—	1,384	21,290
Port of New York	104	8	112	1,723
Delaware River/Bay	26	46	72	1,108
Port of Mobile, AL	3	3	6	92
Port of Lake Charles, LA	20	7	27	415
Houston Ship Channel, TX	46	11	57	877
San Francisco Bay, CA	25	26	51	785
			Annual quantity[c]	
One incineration vessel				
Vulcanus			0.065	1
Apollo			0.100	1.5
30 incineration vessels				
Vulcanus			2.0	30
Apollo			3.0	46

[a] Includes the following commodities:
Sodium hydroxide
Crude tar, oils, gas
Dyes, pigments
Alcohols
Benzene and toluene
Sulfuric acid
Basic chemicals
Paints
Gum, wood chemicals
Insecticides, disinfectants
Miscellaneous chemicals
Gasoline
Jet fuel
Kerosene
Distillate fuel oil
Residual fuel oil
Lubricating oil and grease
Naptha, petroleum solvents

[b] This 1983 quantity is cited in the preamble to EPA's proposed Ocean Incineration Regulation, 50 FR 8226, Feb. 28, 1985. The data are originally derived from the Waterborne Commerce Statistics of the U.S. Army Corps of Engineers. A national total for 1984 was not available at the time of publication of this report.

[c] Estimates based on information obtained from vessel owners.

SOURCE: Office of Technology Assessment, based on U.S. Army Corps of Engineers, *Waterborne Commerce of the United States*, Freight Traffic Tables for Calendar Year 1984.

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[5] The quantity cited by EPA is 8.70 billion barrels of hazardous substances; this is roughly equivalent to 1.38 billion metric tons.

Table 15.—Average Annual Tonnages of Petroleum Products and Chemicals in Mobile Bay (thousands of metric tons)

Commodity	Tonnage[a]
Crude petroleum	3,648
Gasoline, jet fuel, kerosene, fuel oil, and solvents	4,018
Benzene, toluene, and basic chemicals	155
Total	7,821

[a] Annual averages for the period 1977-81.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Based Incineration," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

Table 16.—Shipments of Petroleum and Hazardous Substances in the Gulf of Mexico, Fiscal Year 1983

Commodity	Volume of shipments (mmt)	Number of shipments
Petroleum	270	44,917
Hazardous substances	274	14,978
Total	544	59,895

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Based Incineration," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

increase by about 0.09 percent, or less than 1 per 1,000. If petroleum were included, the increase would be 0.02 percent, or 2 per 10,000.

EPA argues that stricter design and operational requirements applicable to incineration vessels would decrease actual *releases* of hazardous material to the environment even further. Design factors include the smaller tank and total cargo size, double hull, greater maneuverability, and shallower draft of incineration vessels. Operational requirements include weather restrictions and U.S. Coast Guard controls on vessel transit. If such factors are taken into account, **EPA expects releases from each incinerator ship operating in the Gulf to be less than 0.002 percent (or one fifty-thousandth) of those from routine transport of petroleum and hazardous material in the Gulf.**

Incinerator Upset

A second category of accidental release involves any malfunction of the incinerator that results in the release of undestroyed or partially destroyed waste. The expected duration of an incinerator upset would be limited because of the requirement for automatic shutoff of waste to the incinerator in the event of a malfunction. Nevertheless, during this time waste could be expected to enter—and exit—the incinerator under conditions that deviated from permit requirements. A significant amount of combustion would continue to occur because of the remaining heat in the combustion chamber, although the degree of combustion would almost certainly be lower than the efficiency standard.

The amount of additional release would depend on both the length of the upset and the destruction efficiency attained under upset conditions. To illustrate the magnitude of the expected additional release, a worst-case scenario might involve a 10-second delay in waste feed shutoff (see ref. 23; the proposed Ocean Incineration Regulation would allow only 4 seconds). Assuming that during this 10 seconds the destruction efficiency (DE) fell (in the worst case) to 90 percent, the quantity of unburned waste released would be equivalent to 2.8 hours of operation at a DE of 99.99 percent, or 280 hours at a DE of 99.9999 percent.[6]

For a PCB burn requiring a DE of 99.9999 percent, about 10 such upsets during a 12-day (288-hour) burn would reduce the average DE by a factor of 10, to 99.999 percent. If a DE of only 99.99 percent were required (i.e., for incineration of non-PCB wastes), about 1,000 such upsets would be needed to reduce the DE by a factor of 10, to 99.9 percent.

This calculation highlights the fact that the higher the desired DE is, the more sensitive the system is to temporary incinerator upsets. Unfortunately, data are not available on the expected frequency of upsets associated with either land-based or ocean incineration. Nor does evidence exist showing that ocean and land-based incineration technologies experience different frequencies of upset. This issue of variation in operating conditions during extended incineration is one area identified by EPA's Sci-

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[6] A reduction in DE from 99.99 percent to 90 percent would increase the *rate* of emissions a thousand-fold; if the lower DE lasted for 10 seconds, the *amount* of emissions would be equivalent to that normally released in a period 1,000 times longer, or 10 seconds × 1,000 = 10,000 seconds = 2.8 hours. Similarly, if the reduction in DE were from 99.9999 percent to 90 percent, emissions would be equivalent to that normally released in 10 seconds × 100,000 = 1,000,000 seconds = 280 hours.

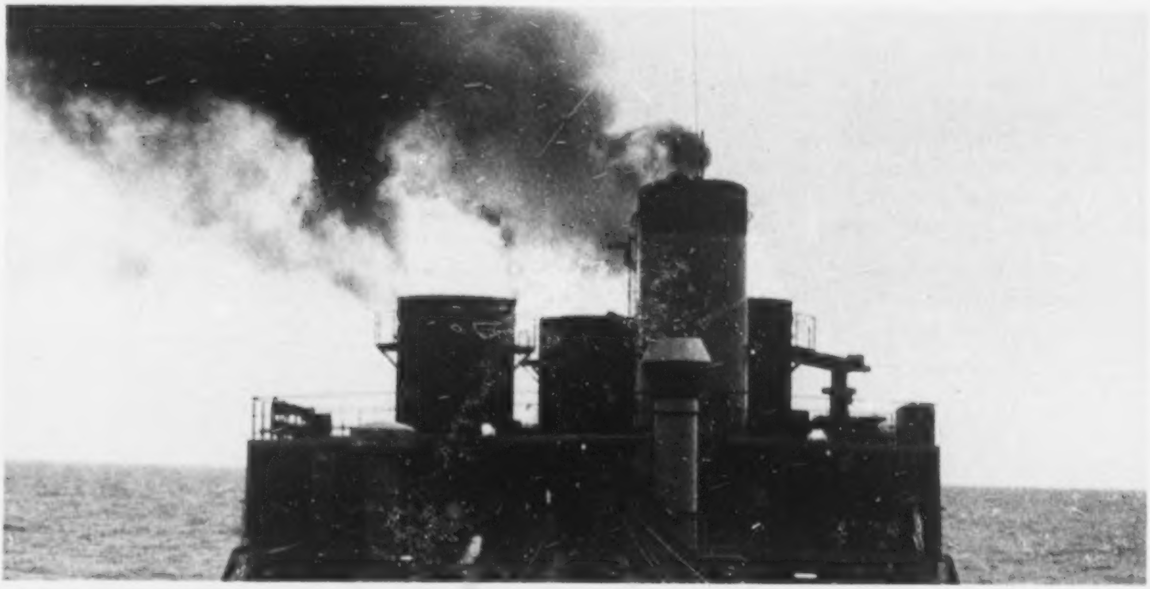

Photo credit: Greenpeace, © 1983 McAllister/Greenpeace

A photograph taken from the deck of the *Vulcanus II* during a November 1983 voyage in the North Sea. Do the flames and smoke exiting the stack typify ocean incineration? One observer reported seeing transient flames and smoke only while the incinerators were being heated by burning fuel oil, not during the burning of wastes (10). Other observers (Greenpeace, cited in ref. 25) claim that the flames and smoke were emitted for an extended period while wastes were being incinerated, in violation of international regulations.

The wastes being burned during this voyage were more aqueous and of less caloric value than those usually incinerated at sea, and were accepted at the request of the Belgian government, which did not want to risk storing the wastes any longer on land. Their incineration apparently damaged analytical equipment on the ship, and led to the ship returning to port after incinerating only half of its cargo (10).

ence Advisory Board (23) as warranting further study and attention.[7]

Fugitive Emissions

Fugitive emissions, which are commonly associated with the transfer and storage phases of incinerator operation, are typically small, slow, or sporadic releases of waste from a variety of sources, including leaking seals, pumps, pipes, valves, and storage tank vents. Unlike spills, most fugitive emissions are released to the atmosphere through volatilization; only rarely are fugitive emissions of a nature or magnitude that would lead to the contamination of marine waters. Such releases can be largely controlled through design modifications and good operating practices.

With respect to estimating magnitude, some fugitive emissions (e.g., small, intermittent pump or valve leaks) are probabilistic (random) in nature. Others (e.g., breathing losses from storage tanks and working losses during the filling and emptying of tanks) are continuous, at least during a particular activity. EPA has estimated fugitive emissions for an ocean incineration operation using an integrated port facility of the type that Chemical Waste Management, Inc., had proposed to build at Chickasaw, Alabama. The calculation assumed that one of the following two wastestreams was incinerated: an annual throughput of 56,000 metric tons of waste containing 35 percent PCBs, or 68,000 metric tons of waste containing 50 percent ethylene dichloride (EDC).[8]

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[7] The Science Advisory Board has suggested that operation on rolling and pitching seas may conceivable affect operating conditions. Opponents contend that there would necessarily be an inherent reduction in the performance of a moving incinerator, while proponents argue that such effects would be negligible and draw an anology to the fuel injection system of a sports car.

[8] Fugitive emissions from these wastestreams would probably be composed largely of volatile waste components, rather than PCB or EDC themselves (app. B in ref. 22).

Under this scenario, EPA calculated that the release of either waste through fugitive emissions would be about 0.7 metric tons annually, or about one-thousandth of 1 percent (0.001 percent) of the total amount of waste handled (22). In each case, storage tanks, not waste transfer and handling, were the major source of emissions, accounting for over 80 percent of the total release.

EPA also estimated fugitive emissions from an ocean incineration system using an intermediate waste storage facility of considerably older design (Chemical Waste Management's facility in Emelle, Alabama). EPA found that fugitive emissions could be expected to increase because of two factors: first, the extra transfers of waste to and from the Emelle facility; and second, the less airtight design of the Emelle storage tanks. Total fugitive emissions under this scenario would be 4.9 and 5.5 metric tons annually for the PCB and EDC wastes, respectively (app. B in ref. 22). These levels would be seven to eight times higher than those resulting from the more modern, single-step operation in an integrated port facility like the one that was proposed for Chickasaw.

Fugitive emissions calculated under each of these scenarios represent the largest of all sources of releases for the handling and transfer phases of ocean incineration. Table 17 compares the various sources of releases for three systems: ocean incineration using a modern integrated port facility (e.g., the one planned for Chickasaw); an equivalent land-based incineration system; and ocean incineration using an older intermediate storage facility requiring a two-step transfer procedure (e.g., the existing facility at Emelle). Total expected releases range from 0.002 percent (Chickasaw and land-based) to 0.01 percent (Emelle) of waste throughput.

Table 17.—Average Expected Annual Releases From Storage and Transfer Operations[a] (metric tons per year)

Release source	Planned Chickasaw facility	Existing Emelle facility	Land-based equivalent
Truck unloading/ loading (spills)	0.03	0.1	0.03
Transfer/storage (spills)	0.5	0.4	0.5
Fugitive emissions	0.7	5.2	0.6
Total	1.2	5.7	1.1

[a] An annual waste throughput of 59,000 metric tons is assumed.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Based Incineration: Appendix B," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

Comparison to Land-Based Incineration

Using an approach similar to the one outlined above, EPA has estimated the amount of fugitive emissions that could be expected from the additional waste storage and handling that ocean incineration would entail. This analysis indicated that, after accounting for all phases of operation, releases due to fugitive emissions would be about 15 percent higher for ocean incineration than for land incineration (22).

Comparison to Other Sources of Fugitive Emissions

Data to compare levels of fugitive emissions from ocean incineration to levels from other sources are generally lacking. Numerous other sources exist at U.S. ports, given the very large quantities of hazardous materials handled by such ports. For example, in the Port of Mobile, about 30 waterfront facilities are currently licensed to handle or store hazardous substances (22). In addition, there are, of course, thousands of other facilities located throughout the United States that handle such substances.

Normal Stack Emissions

Because incineration cannot completely destroy wastes, stack emissions have at least the potential to contain harmful levels of hazardous substances and to convey them to the environment. These substances include:

- unburned waste;
- products of incomplete combustion (PICs);
- toxic metals; and
- acid gases (hydrochloric acid, sulfur oxides, and nitrogen oxides).

The following discussion addresses the quantities of each of these classes of emissions that could be expected to be released to the environment through ocean incineration.

Unburned Waste

This category of wastes is defined (in a regulatory sense) through the selection of a few compounds considered to be representative of the entire waste. The selection is based on one of two criteria: the compounds are present in the waste in high concentration or are judged to be particularly difficult to destroy through incineration. These compounds are termed principal organic hazardous constituents, or POHCs. The regulatory advantage of such a system is that destruction efficiency need only be measured for a small set of POHCs, because their destruction to a particular level is assumed to indicate equal or greater destruction of all the unmeasured components of the waste. Potential shortcomings of this definition are discussed at length in chapter 2.

If the assumptions behind the definitions of POHCs and DE are accepted, and if the desired DE is actually achieved, then the quantity of unburned waste released through stack emissions can be calculated in a straightforward manner. The quantity is simply the product of the unburned fraction of the waste ([100 − DE] ÷ 100) and the total quantity of waste burned. Thus, if an incineration vessel burned 50,000 metric tons of a waste containing 35 percent PCBs in a given year, and if the burns met the DE standard of 99.9999 percent, the quantity of unburned PCBs released would be:

$$\frac{100 - 99.9999}{100} \times 50{,}000 \times 0.35 = \text{0.0175 metric tons, or 17.5 kilograms (38.5 pounds) annually}$$

The magnitude of such releases would be extremely sensitive to changes in the DE. For example, if a DE of only 99.99 percent were achieved, almost 2 metric tons of PCBs would exit the stack annually.

The unburned waste emitted by an incineration vessel would be released over a rather large area, because of the movement of the ship during incineration and the dispersion of the plume after release. This material would be further dispersed upon entry into the sea, due to currents and wave action, although there is potential for concentration of emissions in the surface microlayer (see ch. 9).

The significance of releases of unburned waste to the environment is unresolved. One approach commonly used for evaluating significance is to compare expected releases from ocean incineration with releases from other sources. Ocean incinerator emissions are typically released to the atmosphere (unless a seawater scrubber is employed), but they generally settle over the ocean surface, so the contributions of other sources to both the atmosphere and marine waters are germane. Available data for each of these environments are discussed below, using the example of PCBs.

Releases to the Atmosphere.—In the Gulf of Mexico, ambient (i.e., background) concentrations of PCBs in the atmosphere have ranged between 0.05 and 0.5 nanograms per cubic meter (ng/m^3) (app. I in ref. 22). This atmospheric concentration is estimated to result in 7 to 70 grams of PCBs being annually deposited onto each square kilometer of the Gulf's surface (g/km^2 per year). Using this rate of deposition, EPA has estimated that each year between 10 and 100 metric tons of PCBs enter the waters of the Gulf from the atmosphere (app. I in ref. 22).

Using this range as a measure of the background flux of PCBs entering the waters of the Gulf from the atmosphere permits an estimation of the increase that could be expected to occur because of ocean incineration. The area of the ocean surface affected by the incinerator plume is estimated to be about 90,000 square kilometers (app. I in ref. 22). Assuming a throughput of 50,000 mt of 35 percent PCBs and a DE of 99.9999 percent, the estimated flux of unburned PCBs from ocean incineration would be about 0.2 g/km^2 per year.[9] This would yield an increase above background flux of 0.3 to 3 percent over the affected area.

Averaged over the entire Gulf, these data indicate that each incineration vessel operating at a DE of 99.9999 percent would cause a 0.02 to 0.2 percent increase in the quantity of PCBs entering the water from the atmosphere. At the upper end of this range, an increase in the number of vessels operating in the Gulf or a decrease in the DE achieved could result in a significant increase above background.

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[9] 17.5 kg/yr ÷ 90,000 km^2 = 0.2 g/km^2 per year.

Releases Directly Entering Marine Waters.—PCBs also enter marine waters from a variety of other sources, including waste discharges, dumping, and rivers. For comparative purposes, table 18 lists several estimates of direct PCB inputs to various marine waters from various sources.

The data indicate that ocean incineration employed on a modest scale would cause an incremental increase in the total input of PCBs to marine waters. Clearly, the relative magnitude and significance of such an increase would also vary with respect to location. For example, in contrast to most of the inputs from sources shown in table 18, the emissions from ocean incineration would be expected to enter marine waters at considerable distances from the coast. At these deep ocean sites, the emissions could represent a greater fractional input of PCBs, but would be dispersed over a much larger volume and have less adverse impact on marine life or humans. Unfortunately, few data are available with which to assess the absolute significance of the consequences of the incremental increase in PCBs that would be caused by ocean incineration (see ch. 9 for a discussion of one study).

Table 18.—Estimated Inputs of PCBs to Various Marine Waters

Affected waters: source	Annual PCB loading (kg/yr)
New York Bight:[a]	
Sewage sludge dumping	600-2,000
Dredge materials dumping	3,500
POTW discharges	200-1,000
Upstream sources	3,100
Southern California Bight:[b]	
Sewage	2,000
One incineration vessel at 99.9999% DE[c]	18
One incineration vessel at 99.99% DE[c]	1,800

[a] J. O'Connor, J. Klotz, and T. Kneip, "Sources, Sinks and Distribution of Organic Contaminants in the New York Bight Ecosystem," *Ecological Stress and the New York Bight*, G. Mayer (ed.) (Charleston, SC: Estuarine Research Federation, 1982), pp. 631-653.

[b] M. Connor, "Statement on Incineration of Hazardous Waste At Sea," in Hearing Before the Subcommittee on Fisheries and Wildlife Conservation and the Environment and the Subcommittee on Oceanography of the House Committee on Merchant Marine and Fisheries, 98th Cong., 1st sess., Dec. 7, 1983, Serial No. 98-31 (Washington, DC: U.S. Government Printing Office, 1984).

[c] Assumes a throughput of 50,000 metric tons per year of 35% PCB-laden waste. EPA has proposed the higher DE of 99.9999% for ocean incineration of PCBs.

SOURCE: Office of Technology Assessment.

Products of Incomplete Combustion (PICs)

Data on the formation of PICs are scant for both land-based and ocean incineration. Indeed, EPA's Science Advisory Board has identified the lack of data on the formation of PICs as a major gap in our understanding of incineration, one that precludes an accurate assessment of the full extent of exposure and the impacts of incinerator emissions.

Emissions of PICs were studied in each of the previous U.S. ocean burns, and in a number of land-based incineration trials. Many questions remain regarding the adequacy of sampling and analysis undertaken during the trials, especially with respect to identifying and detecting PICs. The most glaring shortcoming, which was common to virtually all such measurements, was that only a small fraction of all compounds in the emissions (both parent compounds and PICs) was actually identified and individually measured (app. E in ref. 22). Thus, the fraction of emissions that is actually PICs, as opposed to residual parent compounds, is unknown.

This factor alone can lead to underestimation of PIC emissions by several orders of magnitude. For example, in past burns the sum of the amounts of individually identified and measured PICs typically accounted for about 1 percent of the total unburned hydrocarbons present in emissions (app. E in ref. 22).

Moreover, in most past trial burns, measurements were attempted for only a few PICs. In the ocean incineration trials involving PCBs, for example, analysis was performed for only a single PIC: tetrachlorodibenzo-p-dioxin (TCDD).

Other sources of uncertainty in estimating PIC emission rates from existing data include the following (app. E in ref. 22):

- inconsistency in definitions of what constitutes a PIC;
- variations in sampling procedures and detection limits for PICs;
- inconsistency in lists of compounds for which sampling and analyses were undertaken;
- variations in waste feed, which is thought to be a partial determinant of PIC composition; and
- variations in incinerator type and operating conditions.

What is needed is a systematic examination of PICs to provide a consistent and comparative set of data for evaluating both land-based and ocean incineration. Currently, both the quality and quantity of existing data are insufficient to provide the basis for any sound scientific conclusions.

Toxic Metals

Because ocean incinerators would be expected to burn only liquid wastes with low solids content, metal emissions would be directly proportional to the quantity of metals present in the waste feed. Essentially all metals present in the waste would exit the stack during the course of the burn.

EPA has proposed placing a regulatory limit on allowable concentrations of metals in *wastes accepted for incineration at sea* (see ch. 7). Each of 14 specified metals would be limited to no more than 500 parts per million (ppm) in such wastes. At a throughput of 50,000 metric tons annually, a maximum of 25 metric tons (mt) of each of these metals would be released through incineration.

In addition, the proposed Ocean Incineration Regulation would further limit the concentrations of certain of these metals in the *final blended waste* to be incinerated. This further limitation would be accomplished through compliance with an environmental performance standard based on water quality criteria for each metal (see ch. 7). EPA has calculated the maximum quantity of particular metals that could be emitted without exceeding applicable water quality criteria, using a model for plume dispersal and surface water mixing. For 3 of the 14 specified metals, the model requires a waste concentration of less than 500 ppm. Allowable concentrations of these three metals, along with resultant annual emissions (again assuming an annual throughput of 50,000 metric tons), are shown in table 19 (50 FR 51363, Dec. 16, 1985).

Because EPA would not limit the *aggregate* quantity of metals allowable in waste to be incinerated at sea, each individual metal could theoretically be present up to its individual limit. This would place a maximum theoretical limit on total emissions for all 14 metals, calculated as follows: 1.1 mt (silver) + 0.5 mt (mercury) + 17.5 mt (copper) + 275 mt (11 other metals at 25 mt each) = 294 metric tons/year.

Table 19.—Maximum Concentrations of Three Metals Allowed in Wastes To Be Incinerated At Sea

Metal	Allowable concentrations (parts per million)	Expected emissions[a] (metric tons/year)
Silver	21.3	1.1
Mercury	9	0.5
Copper	350	17.5

[a] Assumes an annual throughput of 50,000 metric tons.

SOURCE: U.S. Environmental Protection Agency, 50 FR 51363, Dec. 16, 1985.

This calculation greatly *overestimates* total metal emissions, because no waste would be likely to contain all 14 metals at concentrations even approaching the maximum levels indicated above. The few available data that quantify the metal content of wastes likely to be incinerated at sea indicate that the concentration of individual metals in liquid organic wastes is typically one to three orders of magnitude lower than the 500 ppm standard (3). The metal content of wastes actually incinerated at sea in Europe and the United States is comparably low (1,9,14).[10] Nevertheless, *in the following comparisons, emissions of metals at the theoretical maximum are used as a means of considering* **worst-case** *conditions.*

Comparison With Other Releases of Metals to Marine Waters.—Metal emissions expected from ocean incineration may be compared with inputs of metals into marine waters from other sources.

Coastal Waters.—Resources for the Future (16) developed a database that estimates marine discharges of seven different metals (arsenic, cadmium, chromium, copper, lead, mercury, and zinc) from land-based sources. Table 20 indicates their estimate of the total amount of these metals discharged annually to the Gulf of Mexico. These inputs can be compared to the theoretical maximum input of the same seven metals that would result from the operation of an incineration vessel.

The data indicate that land-based sources annually deposit about 5,600 metric tons of these seven metals in the Gulf of Mexico. In contrast, based on the proposed limits for ocean incineration, the

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[10] The PCB waste that Chemical Waste Management, Inc. (4), proposed to incinerate in the recently canceled EPA research burn contained four metals at detectable levels: chromium (35 ppm), lead (61 ppm), nickel (16 ppm), and zinc (61 ppm).

Table 20.—Comparison of Inputs of Seven Metals to the Gulf of Mexico From Incineration and Land-Based Sources (metric tons)

Metal	Annual land-based loading to Gulf[a]	Maximum annual incinerator emission[b]	Maximum percent increase due to incineration
Mercury	27	0.5	1.9
Copper	628	17.5	2.8
Cadmium	645	25.0	3.9
Arsenic	757	25.0	3.3
Lead	828	25.0	3.0
Chromium	1,317	25.0	1.9
Zinc	1,405	25.0	1.8
Total	5,607	143.0	2.6

SOURCES: [a]Resources for the Future, Renewable Resources Division, *Pollutant Discharges to Surface Waters for Coastal Regions*, prepared for the U.S. Congress, Office of Technology Assessment (Washington, DC: February 1986).
[b]EPA proposed Ocean Incineration Regulation 50 FR 8222, Feb. 28, 1985.

theoretical maximum on incinerator emissions would be 143 metric tons per ship per year.[11] Thus, even if incinerated wastes contained the maximum allowable amounts of these metals, each incineration vessel operating in the Gulf would increase the input of these seven metals by about 2.6 percent.

Adding estimates for a number of metals obscures the fact that significant variation commonly exists in the amount of various metals in wastes. This is true for both incinerable wastes and the other sources of metal inputs discussed above. The variation takes on greater significance in light of the fact that metals differ significantly with respect to human and environmental toxicity.

To illustrate this variation, table 20 indicates the quantities of individual metals contributed by land-based sources and (in the worst case) by operation of an incineration vessel. The data indicate that mercury and zinc are discharged in the smallest and largest amounts, respectively, from land-based sources; inputs of zinc into the Gulf are more than 50 times greater than inputs of mercury.

Also shown in table 20 is the maximum percent increase in inputs of each of the seven metals that would result from the operation of an incineration vessel. Interestingly, despite the fiftyfold difference in the actual *quantity* of mercury and zinc entering the Gulf, the predicted *relative* increases in the inputs of these two metals resulting from incineration are almost identical (1.9 percent for mercury versus 1.8 percent for zinc). This similarity is due to the fact that the proposed limitation on incinerator emissions specified for zinc is fiftyfold higher than that proposed for mercury.

Finally, the data in table 20 indicate that, even in the worst case, the incremental increase in metal inputs caused by incineration would be small for all seven metals, ranging between 1.8 percent (zinc) and 3.9 percent (cadmium).

Other available data on toxic metal inputs to coastal marine waters include estimates for six metals in the New York Bight (13) and eight metals in the Southern California Bight (24). The sources considered in these studies included municipal and industrial wastewaters, atmospheric deposition, and storm runoff. These data indicate annual metal inputs of about 3,500 metric tons (in the Southern California Bight) and 24,500 metric tons (in the New York Bight). Using maximum emissions limits calculated for these metals, one incinerator ship could theoretically contribute about 4 percent (Southern California) and 0.5 percent (New York) of the respective metal burdens already entering these marine waters.[12]

Open Ocean Waters.—Currently some 300,000 metric tons of acid and alkaline wastes are directly dumped into the ocean each year (7). This practice is expected to continue for the foreseeable future. The maximum quantity of five toxic metals

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[11] 17.5 mt (copper) + 0.5 mt (mercury) + 125 mt (5 × 25 mt for the other five metals) = 143 mt per ship per year.

[12] The emissions from ocean incineration, in contrast to these coastal inputs, would be expected to enter marine waters at considerable distances from the coast. At these ocean sites, they might be a greater fraction of total inputs, but also could be expected to disperse over a much larger volume and to cause less adverse impact on marine life or humans.

(cadmium, chromium, copper, lead, and zinc) present in this waste is estimated to be about 630 metric tons (7). Relative to the maximum theoretical limit on incinerator emissions for these five metals (117.5 metric tons annually), the amount dumped directly into the ocean is about five times greater than the amount an incinerator vessel would emit in the worst case.

As a final comparison, metal emissions from ocean incineration can be compared to the quantity of metals present in sewage sludge that is dumped in the ocean. An estimate for the concentrations of the five predominant metals (cadmium, chromium, copper, nickel, and zinc) present in New York City's sewage sludge was developed for the City's Department of Environmental Protection (ref. 12, cited in ref. 17).[13] The ocean dumping of New York City's sewage sludge is estimated to contribute approximately 540 metric tons annually of these five metals, or almost five times the maximum theoretical quantity of these same metals that one incinerator ship could emit in a year. Because New York City's sewage sludge represents only about half of the total amount currently dumped in the ocean (11), this source of metals to the marine environment is even larger than the above comparison indicates.

Comparison With Land-Based Incineration.—Land-based incinerators that would otherwise exceed the particulate standard specified under the Resource Conservation and Recovery Act (RCRA) (see ch. 7) are required to be equipped with stack scrubbers designed to control particulate emissions. Because most metals are strongly bound to particulate matter, scrubbers should significantly reduce metal emissions from hazardous waste incineration.

EPA (22) compared expected emissions of metals from land-based and ocean incineration, using a model liquid wastestream containing 100 ppm of each of four metals (arsenic, cadmium, chromium, and nickel). Arsenic is the most volatile of these, and EPA estimates that scrubbers remove only about 50 percent of it; the other three metals are assumed to be removed at 90 percent efficiency. Using these assumptions, EPA predicts that total metal emissions from land-based incineration of this model wastestream would be one-fifth of those from ocean incineration.

EPA's estimates of the scrubbers' removal efficiencies might be too high for the incineration of *liquid* wastes, because resulting particulates would fall at the low end of the particulate size range and would be removed at a lower efficiency than average (2). Nonetheless, incineration of waste at sea would clearly result in greater emissions of metals than incineration of the same waste on land at facilities equipped with scrubbers.

Comparison With Background Metal Concentrations in the Open Ocean.—EPA used an atmospheric plume/ocean transport model to estimate the rate at which metals would be deposited and how large an area would be affected by emissions from ocean incineration. For the model (4-metal) wastestream described in the previous example, the total amounts of each of the four metals deposited per unit area were calculated. The subsequent mixing of metals in seawater was explored under three scenarios and the resulting metal concentrations were calculated. Table 21 presents these scenarios and concentrations (app. I in ref. 22).

Some limited field data provide estimates of background metal concentrations in the open ocean. Background concentrations were calculated for the upper 60 meters, allowing a direct comparison to the estimated input from ocean incineration under Scenario 3. Table 22 presents the results of this comparison (App. I in ref. 22).

These data indicate that, for mixing to 60 meters,[14] three of the four metals would be well below background. Only cadmium could be expected to exceed its very low background concentration; its level in the affected area would roughly double

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[13] New York City's sewage sludge, as well as that from several other sewerage authorities in New York and New Jersey, is currently dumped at a site in the New York Bight. Under current regulations to be completely in effect by the end of 1987, all of this sludge, as well as that from two newly constructed treatment plants in New York City, is to be dumped at the 106-mile Sewage Sludge Dump Site, located immediately adjacent to the proposed North Altantic Incineration Site.

[14] EPA's proposed Ocean Incineration Regulation (50 FR 8245, Feb. 28, 1985) would define the release zone for incinerator emissions as comprising the upper *20 meters* of surface water; this represents an estimate of the depth of the surface thermocline, above which the initial mixing would be expected to occur. Initial mixing would be defined as "dispersion or diffusion of incinerator emissions into the receiving water which occurs within four hours after release from the incinerator" (50 FR 8258, Feb. 28, 1985).

Table 21.—Metal Concentrations Resulting From Ocean Incineration, Under Three Different Scenarios for Mixing of Emissions in Seawater

	Resulting concentration[a]
Scenario 1:	
All metals are deposited within the surface microlayer, represented by the upper 0.1 millimeter of the ocean surface in the affected area	320,000 ppt[b]
Scenario 2:	
All metals are evenly mixed in the upper 1 meter of the affected area	32 ppt
Scenario 3:	
All metals are evenly mixed in the upper 60 meters[c] of the affected area	0.53 ppt

[a] Assumes that four metals (arsenic, cadmium, chromium, and nickel) are present in the incinerated waste at 100 ppm each.

[b] ppt = parts per trillion.

[c] EPA's proposed Ocean Incineration Regulation (50 FR 8245, Feb. 28, 1985) would define the release zone for incinerator emissions as comprising the upper 20 meters of surface water; this represents an estimate of the depth of the surface thermocline, above which the initial mixing would be expected to occur.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Based Incineration: Appendix I," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

under this scenario. Even if metals from emissions were confined to the upper 1 meter of water, only cadmium could be expected to exceed its background level; in this case, however, the cadmium level would be about 100 times its background concentration.

In contrast, if all emissions were somehow entirely confined to the microlayer, all four metals would far exceed background levels. This would be true despite the fact that background levels of metals measured in the surface microlayer exceed those measured in surface waters by a factor of anywhere from 1 to 50 (app. I in ref. 22). The significance of the microlayer is an area of considerable controversy, and is discussed in chapter 9.

Acid Gases

Because ocean incineration is not expected to employ scrubbers to remove acid gases, the level of acid emissions can be calculated directly from the chlorine (or other halogen) content of the waste feed. Almost all of the organic chlorine content of wastes would be converted through incineration to hydrogen chloride (HCl) gas, with much smaller amounts exiting in the form of other chloride salts, elemental chlorine gas, or organic chlorine (i.e., as residual POHCs and PICs).

To examine the possibility that incineration of highly chlorinated wastes at sea might exceed the proposed environmental performance standard for HCl (see ch. 7), EPA (50 FR 8245, Feb. 28, 1985) developed a worst-case scenario by assuming the following:

- pure carbon tetrachloride, 92 percent chlorine content, is incinerated at a rate of 25 metric tons per hour;
- all chlorine exits as HCl at a rate of 23.7 metric tons per hour; and
- all HCl is deposited within 100 meters of the ship and mixed to a depth of 20 meters (the estimated depth of the thermocline defining the 4-hour mixing zone), which makes the total volume of the mixing zone 22 billion liters.

Under these extreme conditions, EPA estimated, the resulting decrease in alkalinity of seawater in the mixing zone would be only about 1.3 percent,

Table 22.—Comparison of Metal Inputs From Ocean Incineration to Background Metal Concentrations in the Upper 60 Meters[a] of the Open Ocean

Metal[b]	Upper 60 meters background level (ppt)[c]	Upper 60 meters Scenario 3 level (ppt)	Ratio of background to Scenario 3
Arsenic	1,100	0.53	2,075
Cadmium	0.3	0.53	0.57
Chromium	268	0.53	506
Nickel	146	0.53	275

[a] EPA's proposed Ocean Incineration Regulation (50 FR 8245, Feb. 28, 1985) would define the release zone for incinerator emissions as comprising the upper 20 meters of surface water; this represents an estimate of the depth of the surface thermocline, above which the initial mixing would be expected to occur.

[b] Assumes that these four metals are present in the incinerated waste at 100 ppm each.

[c] ppt = parts per trillion.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Background Report IV: Comparison of Risks From Land-Based and Ocean-Based Incineration: Appendix I," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

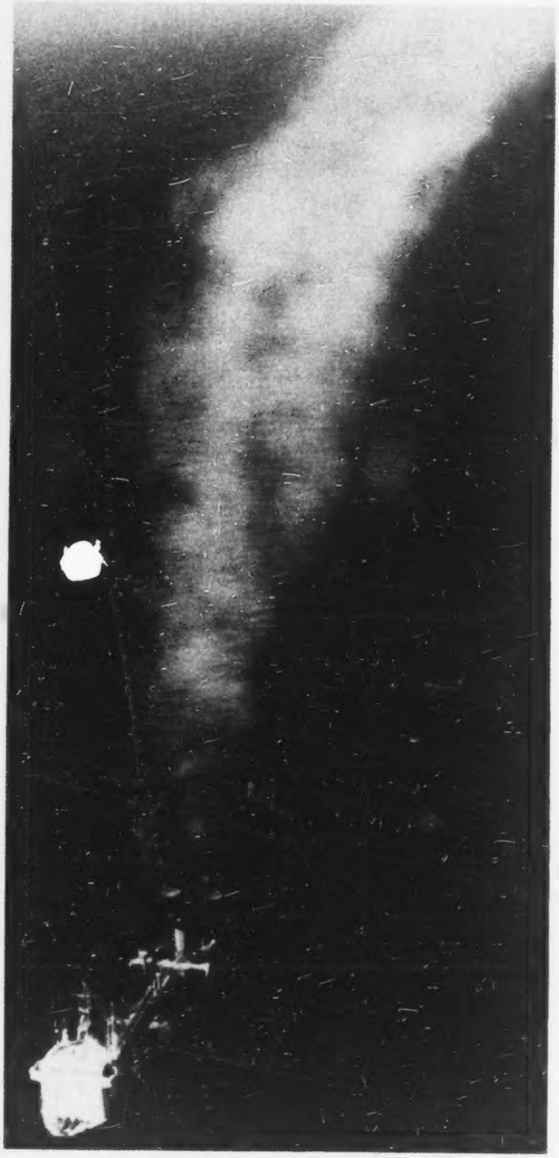

Photo credit: Fred Ward © 1985 National Geographic Society

The *Vulcanus II* incinerator ship, now owned by Chemical Waste Management, Inc., operating in the North Sea. The plume from the ship is composed mostly of steam and hydrochloric acid.

well below the 10 percent change allowed by the proposed standard.

This scenario has been challenged on the basis that it ignores potential impacts that could occur at the higher concentrations of acid that would exist before initial mixing was achieved (i.e., before 4 hours had elapsed). In particular, regions of the surface microlayer that came in direct contact with the incinerator plume might well be exposed to very high (though transient) HCl concentrations. In that event, a large proportion of the organisms in this area could be impaired or possibly killed.

However, given the intermittent nature of ocean incineration, the relatively small size of the affected area, and the high renewal rate of the surface microlayer resulting from new growth and replenishment from adjacent areas, the long-term net loss of biomass would probably be small or non-existent. A more extensive discussion of the nature and significance of the surface microlayer is presented in chapter 9.

Acid wastes are currently directly dumped into the ocean at two sites in the North Atlantic Ocean (7). The rate of dumping of this waste and the size of the dumping area are such that the concentration of acid entering surface waters greatly exceeds that expected from an incineration vessel, by a factor of about 250 (9). In some cases, transient (1 to 4 hours) perturbations in the alkalinity of seawater have been observed following the dumping of acid waste, although no significant effects on marine life have been observed. In contrast, extensive monitoring of past ocean incineration burns has not detected any change in seawater alkalinity (see ch. 11).

Air Pollution Control Device Effluents

This waste, which is generated in very large quantities by land-based incinerators equipped with scrubbers, contains all of the particulates, metals, and acid gases removed from incinerator emissions. EPA (app. F in ref. 22) calculated the following annual composition and quantity of scrubber effluent from a land-based incinerator burning 50,000 metric tons of PCB waste annually and complying with all RCRA standards (waste metal content was assumed to be 100 ppm each of arsenic, cadmium, chromium, and nickel):

- *total quantity*—1.34 million metric tons (more than 99 percent wastewater);
- *chlorine content*—9,300 metric tons (0.7 percent of the total), mostly dissolved salts; and
- *metal content*—4.5 metric tons each of cad-

mium, chromium, and nickel and 2.5 metric tons of arsenic.

Scrubber effluents are typically neutralized, treated to remove particulate matter, and discharged under a Clean Water Act permit as nonhazardous waste. *Sludges* generated through treatment are normally considered hazardous under RCRA, and must be disposed of as such.

SUMMARY AND COMPARISON OF TOTAL RELEASES FROM LAND-BASED AND OCEAN INCINERATION

This section summarizes and compares estimates of the total amounts of waste released by land-based incineration and by ocean incineration. The comparison highlights major differences between these technologies with regard to their potential to cause exposure and adverse impacts.

The EPA incineration study (21) attempted to quantify releases from each phase of operations for both land-based and ocean incineration. The study evaluated the incineration of two different wastestreams: a PCB-containing waste typical of existing stockpiles; and an ethylene dichloride (EDC) waste representing a common (though simplified) industrial chlorinated wastestream. Table 23 presents estimates of how much of each of these wastes would be released during various phases of incineration operations. For a full discussion of the derivation of these estimates and the assumptions and uncertainties involved, the reader should consult the EPA study.

The absence of reliable data, particularly for PIC emissions, and the need to invoke numerous assumptions that are difficult to verify, cast considerable doubt on the estimates and greatly limits their use for setting policy. In particular, the *absolute* quantities probably do not accurately reflect releases from any actual operation.

The following discussion uses the data presented in table 23 for *comparative* purposes only, to identify substantial differences between the releases expected from land-based and ocean incineration.

Within the limits of accuracy of EPA's release estimates, land-based and ocean incineration appear to pose comparable hazards with respect to the overall quantities of wastes and waste products released into the environment. However, the nature and location of the releases also play major roles in determining the potential for humans and the environment to be exposed to or harmed by the releases. By highlighting these differences, chapter 9 compares risks to humans and the environment posed by land-based and ocean incineration.

As an aside, data presented on the last line of table 23 underscores the general advantage of incineration (on land *or* at sea) over land disposal as a means of managing hazardous waste. Expressed as a percentage of total throughput, releases of waste from incineration are minute, indicating the tremendous potential for incineration to reduce both the quantity and degree of hazard associated with these wastes.

Ocean incineration can be expected to release somewhat greater quantities of waste and waste products to the environment than land-based incineration. Increased releases are expected from several phases of ocean incineration operations.

Transfer and Storage.—Ocean incineration would entail at least one extra step, namely the transfer of wastes to the vessel itself. This additional activity would slightly increase the expected quantity of fugitive emissions and the likelihood of a spill occurring.

Ocean Transportation.—Ocean transportation of hazardous waste, which would obviously occur only for incineration that took place at sea, would increase the risk of waste being released through spillage. Assigning an annual average quantity to such an event is highly problematic, because it does not adequately reflect either the probability of a spill occurring or the size of the spill. Available data strongly suggest that a marine spill from an ocean incineration vessel represents a very low-probability event; however, it is equally clear that the consequences of such an event could be catastrophic (see ch. 9).

Table 23.—Summary of Annual Incineration Releases for Two Model Wastestreams

	PCB wastes		EDC wastes	
Assumptions:				
Concentration of PCB or EDC	35%		50%	
Metal content (As, Cd, Cr, Ni)	100 ppm each		100 ppm each	
Annual throughput	50,000 mt		68,500 mt	
Destruction efficiency	99.9999%		99.99%	
Use of modern transfer facility	Yes		Yes	
	Ocean	Land	Ocean	Land
Estimated releases (mt/yr)[a]:				
Land transportation	2.1	2.1	2.7	2.7
Transfer and storage	1.2	1.1	1.2	1.1
Ocean transportation	0.6	—	0.8	—
Subtotal	3.9	3.2	4.7	3.8
Normal stack emissions:				
Unburned wastes	0.1	0.1	6.8	6.8
PICs[b]	<<0.1	<<0.1	20.6	0.6
Metals	22.4	4.5	27.4	5.5
Stack subtotal	22.5	4.6	54.8	12.9
Scrubber effluent metals	—	17.9	—	21.9
Total releases (mt/yr)	**26.4**	**25.7**	**59.5**	**38.6**
(as percent of throughput)	0.053	0.051	0.087	0.056

[a] The releases from land ocean transportation and from transfer and storage include both routine (e.g., fugitive emissions) and accidental releases. For releases due to accidental events such as spills or incinerator upset, the estimates presented here must be interpreted with caution since they represent long-term averages; actual releases from such events are probabilistic, and in a given year could range from zero to a very large amount.

All estimates have been rounded up to the nearest 0.1 metric ton for ease of calculations. Use of a scrubber is assumed for land incineration.

[b] Estimates of PIC emissions are far more uncertain than the other rough estimates presented here, and are of questionable use even in the crude comparison for which these data are intended. See text for a discussion of the variation in these values between land and ocean modes and between PCB and EDC wastestreams.

The symbol "<<" indicates that the estimated value is much less than 0.1 metric tons.

SOURCE: U.S. Environmental Protection Agency, Office of Policy, Planning and Evaluation, "Summary and Conclusions," *Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes* (Washington, DC: 1985).

For these reasons, comparing the risks of spills from incineration vessels to the risks of spills from marine transportation of hazardous substances in general is more appropriate than comparing them to transportation risks from land-based incineration. This more appropriate comparison is presented earlier in this chapter.

As expected, table 23 indicates a somewhat larger (20 percent) release from transporting and handling waste for ocean incineration than for land-based incineration, primarily because of the additional marine transportation that would be involved. The slightly larger releases expected for the EDC waste relative to PCBs is due mostly to the higher assumed throughput.

Incineration.—For both land-based and ocean incineration, and for both types of wastestreams, the incineration process itself would be the major source of expected releases. Each of the three major categories comprising total incinerator emissions is discussed below.

Unburned Waste.—More unburned EDC waste than PCBs would be released because a lower destruction efficiency and a higher annual throughput apply to the EDC waste. Under the assumptions employed, no differences in quantities of undestroyed waste released from land-based and ocean incineration are expected.

PICs.—All of the estimates for PICs are based on extremely limited field data, and cannot serve as the basis for sound generalizations. Thus, EPA's estimates that much higher PIC emissions would be expected from ocean incineration of EDC waste than from land-based incineration, and from burning EDC waste than from burning PCBs, cannot be considered reliable (see previous section on PICs). The only possibly valid generalization is that achievement of a higher DE should logically lead to lower PIC emissions. However, even this straightforward prediction must await further field verification for both land-based and ocean incineration.

Metals.—The quantity of metals resulting from burning the same type of waste is not expected to differ between land-based and ocean incineration. However, the use of air pollution control equipment on some land-based incinerators (which represents a major regulatory distinction between these technologies) is expected to alter the *final disposition* of such metal emissions. For both the PCB and EDC wastestreams, the sum of metals present in stack releases and scrubber effluents from land-based incineration would be equal to the stack releases of metals from ocean incineration.

The data in table 23 suggest that metals account for the great majority of releases from land-based and ocean incineration. These estimates, however, depend entirely on the assumptions made about metal content, which appear to have been substantially overestimated (see previous section on estimating releases of metals).

As is the case with PIC emissions, our present understanding of metal emissions, both qualitative and quantitative, is far from adequate for both land-based and ocean incineration. This major data gap limits our ability to accurately assess the potential for exposure to and harm from incineration of hazardous wastes.

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Chapter 9

Comparison of Risks Posed by Land-Based and Ocean Incineration

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Chapter 9

Comparison of Risks Posed by Land-Based and Ocean Incineration

Each of the several types of releases from land-based and ocean incineration has the potential to adversely affect exposed humans or organisms in marine and terrestrial environments. This chapter explores the key differences between land-based and ocean incineration technologies in terms of the relative risks they pose to human health and to the environment. The chapter also discusses the controversial topic of the surface microlayer's role and the potential for ocean incineration to adversely affect it.

An extensive literature describes the potential for the various aspects of incineration to adversely affect humans and the environment. A full analysis of this literature is well beyond the scope of this study. Moreover, such information rarely provides significant insight into the *comparative* aspects of risks posed by land-based and ocean incineration, partly because many risks cannot be quantified at all, and partly because the fundamentally different nature of the risks often precludes comparison. For example, no accepted methodology exists for comparing a risk to human health with a risk to the marine environment. Yet the comparative aspects of risk are the most relevant in the policy setting that surrounds the issue of ocean incineration.

Because of such limitations, the discussion is restricted primarily to two subjects: the primary types of risks posed by incineration technologies; and the differences between land-based and ocean incineration that bear on the risks each poses to human and environmental health. Where direct comparison of risks is possible, available data are discussed accordingly.

RISKS OF HUMAN EXPOSURE AND IMPACT

One of the major conclusions of EPA's incineration study was that ocean incineration would pose a substantially lower risk of human exposure and health effects than land-based incineration poses. This conclusion was reached by estimating direct exposures and the resulting incremental cancer risks associated with each of the several types of stack releases (POHCs, PICs, and metals).

The analysis, however, has several shortcomings:

- it only evaluated cancer risks, ignoring the potential for other health effects; in addition, the accuracy of the cancer risk estimates is questionable;
- it considered in detail only direct exposure to emissions via inhalation and did not sufficiently assess other routes of exposure (e.g., ingestion of seafood or terrestrial food crops contaminated through bioaccumulation of emission products);
- it analyzed risks for a hypothetical "most exposed individual," and not for the population as a whole; although the level of risk would certainly be greater for the former, relative risks could differ if assessed for the population as a whole; and
- it considered only routine stack releases as sources of exposure and excluded spills, fugitive emissions, and releases due to incinerator upset.

Many exclusions were necessitated by the lack of data required to quantify the risks. For example, data on health effects other than cancer are generally lacking for many of the substances present in stack emissions. Similarly, estimation of risk to an entire population would require a quantification of exposure to various sectors of the population, which would be exceedingly difficult (and controversial) to perform.

Despite these shortcomings, however, *the general conclusion that ocean incineration poses substantially less risk to* **human health** *than does land-based incineration appears both logical and reason-*

able, if judged from within the limits of our current level of understanding. Several lines of reasoning support this conclusion.

The major *releases* from incineration are from the incineration process itself, and incineration at sea is much further removed from human populations than is land-based incineration.

The general population would be *exposed* to substantially fewer releases from ocean incineration than from land-based incineration. The two processes would release roughly comparable quantities of material, and several plausible or demonstrated routes could expose humans to waste products released even in the open ocean. Such factors as atmospheric and ocean dilution volumes, the relative human dietary intake of marine versus terrestrial food products, and distance, however, would lessen the exposure from ocean incineration.

EPA's estimates assign the major portion of incremental cancer risk to metal emissions, which are predicted to be higher for ocean incineration because scrubbers would not be required on incineration vessels. Nonetheless, the risks to human health from exposure to metals would probably not be greater for ocean incineration than for land-based incineration, for the following reasons:

- The 55 percent of land-based incinerators not equipped with scrubbers would release metals in the same uncontrolled fashion as ocean incinerators, but because land-based incineration occurs closer to humans, it would produce a higher exposure.
- Regulations governing land-based incineration do not specify limitations on metal content of wastes, as would the proposed regulation for ocean incineration.
- Although land-based incineration regulations control particulates (but not metals per se) and require scrubbers for wastes that would otherwise exceed the standard, the removal efficiency of scrubbers for metals is probably lower than assumed by EPA, particularly for the liquid wastes relevant to this discussion. Incineration of liquids generates only low levels of smaller than average particulates, and scrubbers operate less efficiently at low particulate density and on small particulates (1).
- Although toxic metals removed by scrubbers are deposited in scrubber effluents and sludges, EPA's study did not assess the considerable potential for human exposure to these wastes, for example, via groundwater for landfilled sludges, and drinking water for discharged effluent.

One recent study modeled the exposure of humans to emissions of PCBs, through both direct and indirect pathways, and concluded that exposure would be considerably lower from ocean incineration than from land-based incineration (9). For land-based incineration, the study evaluated human exposure to PCBs that could result from inhalation, drinking water, and diet (terrestrially grown food); for ocean incineration, it evaluated human exposure that could result from a seafood diet (fish and shellfish). In considering dietary exposures to PCBs, the study compared *average* exposures from land-based incineration with *worst-case* exposures from ocean incineration (i.e., individuals were assumed to receive *all* seafood from the ocean incineration site).

The study concluded that dietary exposures to PCBs would still be 20 times higher from land-based incineration. Predicted exposures from inhalation were two orders of magnitude higher for land-based incineration, and predicted exposures from drinking water were comparable to those expected from ingestion of seafood.

Because of a lack of information, the study did not model exposures that would result from the concentration of emissions in the ocean surface microlayer (see later section in this chapter). If the microlayer is an important contributor to the marine food chain, the relative magnitude of dietary exposures could be altered significantly.

One possible major exception to the generalization that ocean incineration would pose no greater risk to human health than land-based incineration poses is the unlikely event of a catastrophic spill, particularly one occurring close to shore. Estimating the extent of health risk from direct and indirect human exposure to spilled waste materials is fraught with difficulties. However, such risks would probably, under some circumstances, be much greater for ocean incineration than for land-based incineration, because the size of a spill could be expected to be much greater at sea than on land.

Despite many years of operating experience, the actual impact of land-based incineration has been very difficult to study and ascertain. In part, this is because of a general lack of understanding of two issues identified by EPA's Science Advisory Board (16)—the transport and fate of incineration products in terrestrial ecosystems and the use of monitoring strategies and technologies that are less than state-of-the-art. Environmental monitoring is complex on land, however, because similar emissions can arise from other land-based sources of pollution, greatly complicating attempts to assign exposure or impacts to land-based incinerators or even to study the transport and fate of incinerator emissions.

RISKS OF ENVIRONMENTAL EXPOSURE AND IMPACT

Comparing the environmental consequences of land-based and ocean incineration is much more difficult (if not impossible) than comparing their risks to human health, because marine and terrestrial environments and the potential impacts involved are so fundamentally different. Even when data allowing risks to be quantified are available, no accepted means exist for comparing the risks faced by different organisms or environments.

Because of these difficulties, the discussion in this section is limited to a description of the nature and expected extent of environmental risks posed by ocean incineration, and a sketch of aspects or resources unique to marine environments that might be affected by ocean incineration. Potential adverse effects of routine emissions and of accidental spills are discussed separately.

Impacts From Routine Emissions

The first area affected by incinerator emissions would be the ocean surface contacted by the incinerator plume. Particular attention has been focused on the so-called **surface microlayer**, represented by the *skin* or uppermost fraction of a millimeter of the ocean. This micro-environment has been shown to contain high concentrations of both living organisms and contaminants, relative to the water immediately below the surface. Information concerning the nature and ecological significance of the microlayer habitat is only beginning to emerge. With respect to ocean incineration's potential effect on it, EPA's Science Advisory Board (16) has identified the surface microlayer as a priority for further study and testing, partly because of its probable key role in the food chain of the ocean. The current state of knowledge regarding this habitat is discussed later in this chapter.

Various types of marine organisms have the potential to be affected by incinerator emissions. **Plankton**, which are microscopic organisms present in immense numbers in the water column, could suffer both short- and long-term damage from various components of incinerator emissions. During past U.S. burns, attempts were made to sample plankton and to look for short-term effects caused by changes in chlorine content, alkalinity, and the introduction of trace amounts of organochlorine compounds and metals. In addition, physiological indicators of plankton health (chlorophyll and adenosine triphosphate content) were also monitored. Although no effects were detected for any of these parameters, the number and size of samples analyzed may have been too small to detect changes. Moreover, an adequate method of measuring long-term effects has not been developed, so they cannot currently be assessed.

Fish and other swimming organisms near the settling plume might be affected briefly by the changes described above. These effects would be expected to be limited both temporally and spatially because of the mobility of affected organisms and the relatively rapid neutralization or dilution of the residual constituents to background levels.

Somewhat longer term effects can be studied by using certain physiological measures of stress caused by exposure to toxic pollutants. Laboratory and field experiments conducted during one of the past U.S. ocean burns, in fact, detected such a stress response (ref. 11; also see discussion of past U.S. burns in ch. 11). Activation of an enzyme-detoxification system was detected in fish taken from the exposure zone, and similar results were obtained in parallel laboratory tests involving direct exposure of fish to raw (unburned) waste material. In the laboratory studies, enzyme levels decreased to normal levels when fish were returned to clean water, indicating that the response was a transient one.

These experiments provided the first direct evidence for an environmental effect attributable to ocean incineration. Because the response was transient and the duration and scale of the experiment were limited, the full significance of these results cannot yet be determined. EPA plans to study this phenomenon further as part of the Agency's Ocean Incineration Research Strategy (14).

Longer term or more subtle impacts (e.g., effects on reproduction or growth) are much more difficult to study, especially in the field, and have not been examined during past ocean burns. EPA's Research Strategy includes limited efforts to examine such effects.

Bottom-dwelling organisms could be affected by contaminants adsorbed to particles that eventually became incorporated into bottom sediments. Because water at existing or proposed incineration sites is deep, such effects would probably be minimal, exceedingly difficult to detect, and long term in nature.

Prior to settling or dispersion of the incinerator plume, there is potential for adverse impact on **migratory and open-ocean species of birds**. Both the Gulf incineration site and the proposed North Atlantic site lie in known migratory routes. The routes are extremely broad, and the incineration sites cover only a small fraction of their width. These facts, together with the intermittent nature of incineration activities and the typically high altitude of migratory paths, should limit the extent of this type of impact. However, migrating birds often seek out ships or other platforms for resting; indeed, some reports suggest that birds may be attracted to incineration vessels, particularly at night when the glow of the furnaces is visible for considerable distances. Whether birds would avoid the incinerator plume itself is not known (6,18).

The potential for adverse impact to **marine mammals and turtles** has also generated considerable debate. The proposed Ocean Incineration Regulation would require an endangered species assessment to be conducted and periodically updated, in compliance with the Endangered Species Act.

Several endangered or threatened species have been identified in the vicinity of existing or proposed burn sites. This issue has recently been raised in the context of EPA's designation process for the North Atlantic Incineration Site. An Environmental Impact Statement (EIS) on the site completed in 1981 concluded that the site lay in migratory routes for certain marine animals (13). New information from the National Marine Fisheries Service (NMFS), however, indicated that the site also lay within a *high-use* area for several marine mammals, including the endangered sperm whale (2).

Based on EPA's updated assessment of the site from the perspective of endangered species (17), NMFS granted conditional approval to using the site for a research burn (7). Final designation of the North Atlantic Incineration Site will require a more formal biological opinion fully addressing this controversial issue.

Impacts From Accidental Spills

The most severe environmental impacts associated with ocean incineration would be those resulting from an accidental spill of hazardous wastes. There is a general consensus that, under most circumstances, spilled material would be impractical or impossible to clean up, especially as distance from the loading dock increases. Although a spill is considered an unlikely event, the severity of its consequences and the difficulty of cleanup warrant a comprehensive evaluation of the risk involved.

Unfortunately, few data are available for assessing the magnitude of the damage that would result from a major spill of hazardous wastes in marine waters. Innumerable determinants of fate and effects must be understood in order to undertake such an analysis. These include the following:

- *the nature of the waste:* factors such as density and solubility would determine the waste's subsequent behavior (e.g., sinking, floating, or dissolution in the water column);

- *the composition of the waste:* the fate of mixtures of different wastes would be complex and hard to predict;
- *the properties of individual constituents:* factors like toxicity, persistence, and potential for bioaccumulation would dictate subsequent exposure and impact;
- *the location and characteristics of the spill site (harbor, coastline, open ocean):* water depth and bottom terrain; currents, tides and other determinants of dispersal rate; the presence and value of resources; nature and extent of biological activity; and ecological sensitivity would all influence the magnitude of impacts from the spill; and
- *the potential for cleanup or recovery:* the distance from shore and the expense and availability of appropriate technologies would affect response to a spill.

For most hazardous materials, a significant spill in almost any location would result in considerable immediate destruction of biomass and loss of most organisms in and around the spill. Acute effects could result from physical impacts (e.g., smothering of bottom-dwelling organisms, or coating of birds' wings) as well as from the immediate toxic effects of caustic or other highly reactive substances. Chronic effects would be more widespread and long-lasting, particularly for toxic and persistent chlorinated hydrocarbons, which are among the most likely candidates for ocean incineration.

The following discussion of the possible effects of spills focuses on two PCB wastes—one heavier than water (sinking) and one lighter than water (floating)—and on two possible spill locations—either an open-ocean setting, such as the burn site itself, or an enclosed harbor or bay, such as Mobile. Many of the effects described would be likely to occur only in a *worst-case* situation.[1] Effects from materials that differ from PCBs in toxicity or persistence would be more or less severe and long-lasting.

A spill of sinking material in the deep water of the incineration site would probably pose the least hazard, but would also be most difficult to clean up. Acute effects on plankton or other organisms would largely be limited to those caught in the waste mass itself as it descended toward the bottom. Currents and waste solubility, among other factors, could serve to further disperse waste as it passed through the water column, thereby increasing the area of immediate impact. The bottom-dwelling community would be immediately and most heavily affected in this scenario. In the worst case, a significant portion of the organisms in the affected zone could be eliminated, and long-term contamination of bottom sediments could severely limit recolonization. Chronic effects would be most likely for surviving bottom-dwelling organisms, although remobilization of contaminated sediments by bottom currents, bioturbation, or other means could increase the size of the affected area.

A floating waste spilled at the incineration site would probably spread over a broad area relatively rapidly. Damage would be greatest for the surface microlayer and for organisms living in or frequenting water near the surface. A significant portion of such organisms would experience acutely toxic or even lethal effects, whereas organisms with less exposure could be expected to show chronic effects from more gradual accumulation.

Compared to a spill in the open ocean, the consequences of a spill in a confined and shallow area, such as a harbor or bay, would probably be more severe. Planktonic effects from the high concentrations of PCBs could be expected. Because PCBs tend to adsorb strongly to organic matter, organisms like shrimp larvae, which feed on organic matter, could suffer serious acute and chronic effects. In the worst case, a sinking waste would kill most or all bottom-dwelling organisms. Greater opportunities for resuspension of contaminated sediments exist in shallow waters, so continued release of waste materials to the water column could be expected.

A floating waste spilled close to land would probably be the most likely to afford opportunities for partial cleanup. But it could also harm not only marine organisms, but humans and other shore life (e.g., birds, shellfish beds, and wetlands), as well. Volatilization of waste constituents from the surface slick could pose direct inhalation risks to nearby residents. Many or most marine commercial and recreational activities in the region would be affected immediately and possibly for the long term.

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[1] Note that PCBs are only one of many wastes that could be incinerated at sea. Although they are highly persistent in the environment, they are not the most toxic of such wastes (see box B in ch. 3). Large quantities of chlorinated hydrocarbon *nonwaste* materials are routinely transported by sea (see ch. 8).

The potential effects of a PCB spill in the Delaware River and Estuary were recently assessed in relation to a proposed research burn in the North Atlantic Ocean (10). For a spill of about 800 metric tons[2] of waste containing 10 to 30 percent PCBs, three scenarios were modeled: 1) an upstream spill at or near the loading dock in Philadelphia, 2) a midstream spill near Wilmington, and 3) a spill at the midpoint of the Delaware Estuary. Conservative assumptions regarding the dispersion and fate of PCBs were used to generate a "worst-case" prediction.

For the first two scenarios, the results indicated that during the first several hours at a given location, water quality criteria and aquatic toxicity levels would be exceeded and most fish would probably be killed. Predicted long-term concentrations in the river water or sediments would be much lower, probably below those that have been demonstrated to cause any ecological effects. For the third scenario—an estuarine spill—a kill also would occur during the first several hours, affecting fish, plankton, and invertebrates, and in the worst case involving the entire estuary. Long-term effects resulting from sediment contamination could include accumulation of measurable quantities of PCBs in shellfish such as oysters.

Most of the effects discussed above are difficult or impossible to quantify. Much of the criticism of ocean incineration identifies and focuses on the many sources of uncertainty inherent in determining actual risk. Indeed, uncertainty is a clear theme throughout this entire discussion of risks.

Both EPA and its Science Advisory Board recognize that much more information is needed to evaluate the full extent of risks posed by ocean incineration. Both have identified unresolved issues and areas that need further research. The SAB (16) noted the following topics as needing more attention:

- understanding the role of the microlayer in the marine food web and the nature of its apparent high biological activity and ability to trap contaminants;
- field-testing of the numerous models used by EPA in estimating impacts;
- better understanding the routes of exposure, food chains, and community structures in marine environments;
- determining toxicities and bioaccumulation potential of wastes and waste products in marine settings; and
- developing better means of assessing long-term and sublethal effects on marine organisms, communities, and ecosystems.

EPA has developed a research strategy for ocean incineration (14), which specifically addresses many of the remaining areas of uncertainty, and outlines additional research plans in both laboratory and field settings. Table 24 lists the major areas of concern identified in EPA's research strategy.

The SAB emphasized that uncertainty was by no means the exclusive domain of ocean incineration, and that many of the areas the Board identified also applied to land-based incineration and even to other common combustion processes. The discussions in previous chapters concerning risks associated with land-based hazardous waste disposal and with marine transportation of hazardous ma-

Table 24.—Major Areas of Concern Identified by EPA in Its Ocean Incineration Research Strategy

I. Composition of emissions
  A. Development of appropriate sampling and analysis methods
  B. Determination of the composition of emissions from an at-sea PCB research burn
II. Exposure assessment
  A. Incineration research site selection
  B. Environmental baseline sampling
  C. Environmental sampling during research burn
  D. Worst-case exposure scenarios
  E. Laboratory transport testing
  F. Transport model development, atmospheric and aquatic
  G. Transport model validation
III. Biological effects assessment
  A. Acute and chronic toxicity
  B. Bioconcentration
  C. Genotoxicity
  D. Effects on the surface microlayer
IV. Comparative environmental risk/hazard assessment

SOURCE: U.S. Environmental Protection Agency, Office of Water, *Incineration-At-Sea Research Strategy* (Washington, DC: Feb. 19, 1985).

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[2] Equivalent to one-fourth of the capacity of the *Vulcanus II*, corresponding to the loss of the entire contents of two of its eight cargo tanks.

terials are indicative of uncertainties in these areas, as well. It is essential, therefore, to conduct a comparative assessment of risks and to view any single activity such as ocean incineration in as broad a context of related activities or risks as possible.

The Role of the Surface Microlayer[3]

The ocean's uppermost surface, or microlayer, is in many respects an environment unto itself, one that has properties distinct from the sea immediately below and the air immediately above. Yet the microlayer also appears to play a vital, but only poorly understood, role as an interface and medium of transfer between sea and air.

The dimensions and composition of the surface microlayer have not been thoroughly defined. Although it is most commonly visualized as a surface slick, which may be patchy, it is present even when it is not visible. Its thickness, which is mostly defined operationally through sampling procedures, ranges from less than one-tenth of a millimeter to several centimeters. Many studies have demonstrated that the microlayer can be enriched in a variety of materials, including organic matter, metals, toxic organic chemicals, and active populations of organisms (12). The organisms include a wide range of bacteria, minute animals or plants (the surface subset of plankton), and the eggs and larvae of many different fish and crustaceans. Certain species are entirely unique to the microlayer (8).

The enrichment of various materials in the microlayer can result in concentrations that are anywhere from 2 to 10,000 times higher than those found just a few centimeters below the surface (8). However, the level of enrichment varies with time of day, season, weather conditions, location, and the particular substance or organism being considered. This variability greatly complicates the study and definition of the microlayer.

Various mechanisms for depositing and removing materials and organisms from the microlayer have been identified. These include wave and whitecap formation, surface interaction of gas bubbles, the natural buoyancy of eggs and larvae, the hydrophobic (water-repelling) nature of some organic materials, surface flows and currents, and wind action. The combined effect of these mechanisms is a steady turnover, in which loss and replenishment of essentially all components of the microlayer occurs continuously. For example, various organic compounds and metals can remain in the microlayer anywhere from a few seconds to many hours (3). Mixing by surface flows, wave action, or other means drives surface material downward to underlying waters, which is now recognized as an important transport mechanism for materials deposited on the ocean surface (19).

The ecological significance of the living portion of the microlayer is poorly understood. The enrichment of organic matter in the microlayer provides a food source for the minute plants and animals that reside there and accounts for their high densities in the microlayer. These surface organisms, in turn, may play an important role in the marine food web, because they provide a basic food source for the plankton that live in immediately underlying waters (8). These questions are currently under intense study, which should rapidly increase our understanding of the microlayer's role in marine communities.

The microlayer also appears to serve as an essential, if temporary, habitat for the embryonic life stages of many fish and crustaceans, including many commercially important species (e.g., shrimp in the Gulf of Mexico).

The surface microlayer's apparently vital roles and its ability to become enriched in toxic organic compounds and metals raise legitimate concerns over whether accidental spills and emissions from ocean incineration would cause significant environmental damage. Unfortunately, an evaluation of possible consequences must await further study, including the development of an adequate methodology to sample and monitor the surface microlayer.

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[3] This discussion is based on information from papers presented at an EPA-sponsored workshop on the Sea-Surface Microlayer, held in Arlie, VA, on Dec. 18 and 19, 1985.

ADDITIONAL FACTORS RELEVANT TO A COMPARISON OF LAND-BASED AND OCEAN INCINERATION

This section presents several additional points of comparison and contrast relevant to a consideration of hazardous waste incineration technologies. These issues have been raised repeatedly in the debate over ocean incineration and are particularly germane to determination of policy. The following discussion does not attempt to resolve these issues, but it presents common arguments that illustrate the range of existing opinion.

Onsite Versus Offsite Incineration

Ocean incineration is, by definition, an offsite activity, in which the manager of wastes is distinct from the generator of wastes. Virtually all current *commercial* land-based incineration also occurs offsite, whereas *private* incineration typically entails a generator processing wastes in a facility located at the site of generation.

Two concerns are raised about offsite incineration, and indeed, about all offsite hazardous waste management activity. The first is that offsite management generates additional risks (because of extra transportation and handling requirements) that could be avoided by management at the site of generation. The second concern stems from the fact that the party who actually disposes of or treats waste offsite is different from the party who generated it. Some observers believe that the generator's accountability for the generation *and* subsequent handling of waste is substantially weakened, which necessitates elaborate regulatory mechanisms for tracking wastes from "cradle to grave." Furthermore, because the waste managers are paid for rendering their service, these observers fear that profit becomes a primary determinant of how carefully and safely wastes are handled. Addressing this concern requires a more elaborate set of regulations

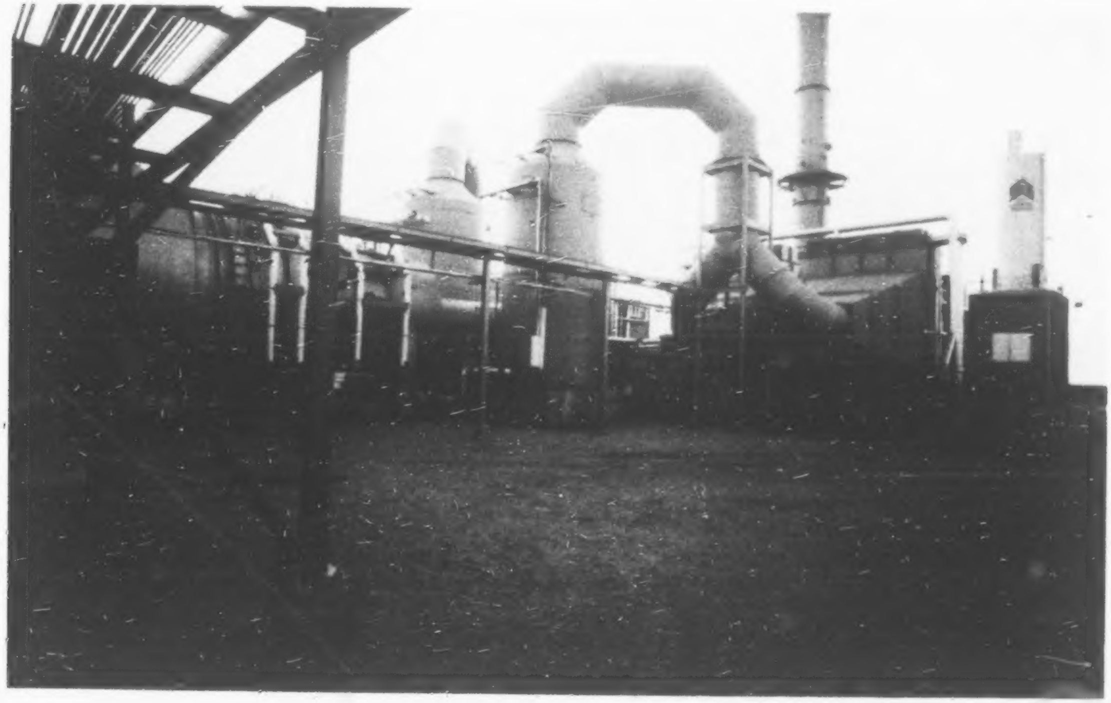

Photo credit: SCA Chemical Services/Air Pollution Control Association

A commercial rotary kiln incineration facility.

to ensure proper waste management than would otherwise be needed.

Many other observers argue, however, that the development of large, offsite management capability is desirable because it centralizes hazardous waste management activities. According to this argument, centralization takes advantage of economies of scale and eases the tremendous regulatory burden of permitting, monitoring, and ensuring the regulatory compliance of many smaller facilities. Moreover, given the number of waste generators that cannot afford to manage their own wastes or use the best technological means available, commercial facilities in the business of managing wastes may be in a better position to do so safely and in compliance with regulatory requirements.

Both arguments have been legitimately raised in the debate over the relative merits of land-based and ocean incineration. Such a debate bears as well on the larger issue of the roles and responsibilities of the public and private sectors in solving complex societal problems such as hazardous waste management.

Cost to Generators

A related issue involves how much generators would have to pay for ocean incineration, relative to the price of commercial land-based incineration. Many critics of ocean incineration argue that it is an inexpensive option that would be used in place of more expensive but environmentally sounder practices. The major reason cited for the low cost of ocean incineration, relative to land-based incineration, is the absence of a requirement for costly air pollution control equipment.

Many widely varying estimates of the cost of ocean incineration have been offered (4,5,15). The reliability of any of these estimates is questionable, however, because the many variables involved are difficult or impossible to determine in advance. Some of the variables include:

- size of the market for incineration of liquid wastes;
- type of wastes, including high-value markets (e.g., PCBs) and low-value markets (e.g., aqueous organic wastes);
- costs of other options for such wastes (competitive pricing);
- regulatory requirements, such as liability insurance levels and monitoring and analysis requirements;
- port and incineration site locations; and
- nature and cost of required port facility development.

In light of such hard-to-predict factors, estimated prices cover a broad range. For example, the following price ranges (expressed in 1983 dollars per metric ton), averaged for several waste types, have been estimated for land-based and ocean incineration and (for purposes of comparison) for landfilling (5):

Landfilling	$ 55 to $240
Land-based incineration	$360 to $500
Ocean incineration	$200 to $400

Other studies exhibit wide ranges and variations in price estimates, but virtually all support several generalizations:

- Incineration, whether on land or at sea, is consistently more expensive than traditional land disposal alternatives. Indeed, cost is cited as the primary reason for generators' minimal use of incineration to date.
- The gap between costs for disposal and incineration is expected to narrow as restrictions on land disposal are implemented and in response to generators' growing concerns about their long-term liability for wastes.
- On an average, ocean incineration is predicted to cost waste generators somewhat less than land-based incineration, although price ranges are likely to overlap substantially. Despite arguments that ocean incineration's lower costs would stem from the lack of a requirement for expensive air pollution control equipment, two operating factors are likely to be equally or more determinative:
  1. ocean incineration's annual throughput would be higher, enhancing income-generating potential; and
  2. ocean incineration would concentrate on a high-value waste market, predominantly on wastes with high chlorine and energy contents and on easy-to-burn liquid wastes,

rather than on a mixture liquids, solids, and sludges.

Whatever ocean incineration's eventual price, it probably will for the foreseeable future lie between the low costs of land disposal and the much higher costs of the new and emerging technologies discussed in chapter 4.

Ease of Monitoring and Surveillance

The fact that ocean incineration occurs far from shore has provoked two reasonable but opposing lines of argument by participants in the ocean incineration debate. Proponents point to the fact that the residual quantities of wastes or waste products released during incineration are far less likely to harm humans if the incineration occurs far from human populations. Opponents, however, consider ocean incineration an "out-of-site, out-of-mind" solution to the hazardous waste problem. Indeed, monitoring and enforcement probably would be more troublesome for an activity that occurs beyond the horizon. In the absence of compensatory measures, the government's (and perhaps equally important, the public's) ability to monitor the activity and to detect regulatory violations could be expected to decrease with distance from shore.

In response to such concerns, EPA has proposed several special regulatory provisions to be required only of ocean incineration. These include requirements for a full-time EPA shiprider on each voyage, use of tamper-proof or tamper-detectable recording devices for all automatic monitoring data, submission of all monitoring and waste analysis data to EPA after each voyage, and, on request, inspections of facilities and records. Not surprisingly, the adequacy of such measures is also the subject of considerable controversy.

Interestingly, a similar line of argument has been applied to private (onsite) incineration and other noncommercial hazardous waste management facilities. Concerns have been raised about the ease with which the government or the public could monitor such operations or could gain access to private information that was in the public interest. These concerns have arisen, for example, in debates over the siting of such facilities.

Degree and Nature of Public Participation

The high degree of public participation (and in general, opposition) in the debate over ocean incineration is somewhat surprising, in light of the commonly heard concern that the ocean has little political representation ("fish don't vote") and is "in no one's backyard." This level of participation partly reflects the fact that designating specific ports and sites for ocean incineration does have clear local and regional consequences. The debate has broadened beyond these concerns, however, and has taken on national dimensions; indeed, a broad-based "ocean constituency" has developed. One result of this phenomenon is that the role of ocean incineration is increasingly being viewed in a broad context, as only one component in the debate over the shaping of a national hazardous waste management strategy.

In contrast, land-based incineration remains a chiefly local concern. Although public concern and opposition to the siting of land-based incinerators is often equally intense, broader issues are less likely to be raised in the process.

The government and the various interest groups working toward solutions to hazardous waste problems have an obligation to recognize and consider the interrelationships between these issues of local and national concern in order to raise the level and scope of the debate.

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Chapter 10

Overview of Federal Laws and Regulations Governing Incineration

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Chapter 10

Overview of Federal Laws and Regulations Governing Incineration

Land-based and ocean incineration are regulated under different primary statutes and regulations. Various additional statutes cover activities (e.g., land transportation) related to both technologies. This chapter provides an overview of the statutory and regulatory framework for land-based and ocean incineration. Table 25 provides a summary of statutes applicable to land-based or ocean incineration or both, along with a description of the regulated activities. Many of the specific details of existing requirements and provisions are reviewed earlier in other chapters.

Table 25.—Summary of Federal Regulatory Framework for Incineration

Statute/regulation	Agency	Activities: Ocean incineration	Activities: Land-based incineration
Resource Conservation and Recovery Act	U.S. Environmental Protection Agency (EPA)	Waste storage Waste content Land transportation Residuals disposal	Waste storage Waste content Land transportation Land-based incineration Residuals disposal
Marine Protection, Research, and Sanctuaries Act	EPA Coast Guard	Ocean incineration	—
Toxic Substances Control Act	EPA	Incineration of PCBs	Incineration of PCBs
Coastal Zone Management Act	States	Activities affecting land or water use in the coastal zone	Activities affecting land or water use in the coastal zone
Hazardous Materials Transportation Act	Department of Transportation	Hazardous waste transportation by truck or rail	Hazardous waste transportation by truck or rail
	Coast Guard	Transportation by water	—
Port and Tanker Safety Act	Coast Guard	Design, construction, certification, operation of incinerator vessels	—
Port and Waterways Safety Act	Coast Guard	Vessel movement through ports; waste storage, transfer at waterfront	—
Endangered Species Act	EPA	Compatibility of designated sites with protection of wildlife	—
Clean Water Act	EPA Coast Guard	Cleanup of spills in territorial waters	Cleanup of spills in inland waters
Comprehensive Environmental Response, Compensation, and Liability Act (Superfund)	EPA Coast Guard	National Contingency Plan, cleanup of spills	National Contingency Plan, cleanup of spills

SOURCE: Office of Technology Assessment.

LAND-BASED INCINERATION

Although hazardous waste incineration has been widely used by industry for some time, explicit regulation of the practice was only recently initiated. The 1976 **Resource Conservation and Recovery Act** (RCRA) provided a mandate to regulate hazardous waste incineration on land, because operations fell under the definition of treatment, storage, and disposal facilities for hazardous waste. Regulations finalized in 1981 (46 FR 7666, Jan. 23, 1981) and amended in 1982 (47 FR 27520, June 24, 1982) established standards for land-based incineration and required that all land-based incineration facilities obtain RCRA operating permits. These regulations specified the basic requirements for land-based incinerator design, performance, permitting, waste analysis, monitoring, and reporting.

Because it is covered under RCRA, hazardous waste incineration on land is effectively exempted from coverage under the **Clean Air Act** (CAA). Municipal waste incinerators, however, are covered under the CAA. New source performance standards for municipal facilities were promulgated in 1981 but include only a single standard for particulate emissions. A numerically identical standard has been incorporated into the RCRA regulations governing land-based hazardous waste incineration.

The **Toxic Substances Control Act**, passed in the same year as RCRA, banned the manufacture of PCBs and was followed by regulations governing their treatment and disposal, including the use of incineration (see box B in ch. 3). Under RCRA, an application to incinerate PCBs requires special approval by the EPA Administrator before authorization can be incorporated into a RCRA (for land-based incineration) or MPRSA (for ocean incineration) permit. Currently, only six incinerators are permitted to incinerate PCBs. These are owned and operated by ENSCO (Arkansas); Rollins Environmental Services (Texas); SCA Chemical Services, owned by Waste Management, Inc. (Illinois); Pyrotech (Tennessee); General Electric (Massachusetts); and EPA (a mobile unit currently stationed in New Jersey). In addition, GA Technologies (California) recently received a permit for a transportable incinerator which, when completed, can be used anywhere in the country for PCB incineration.

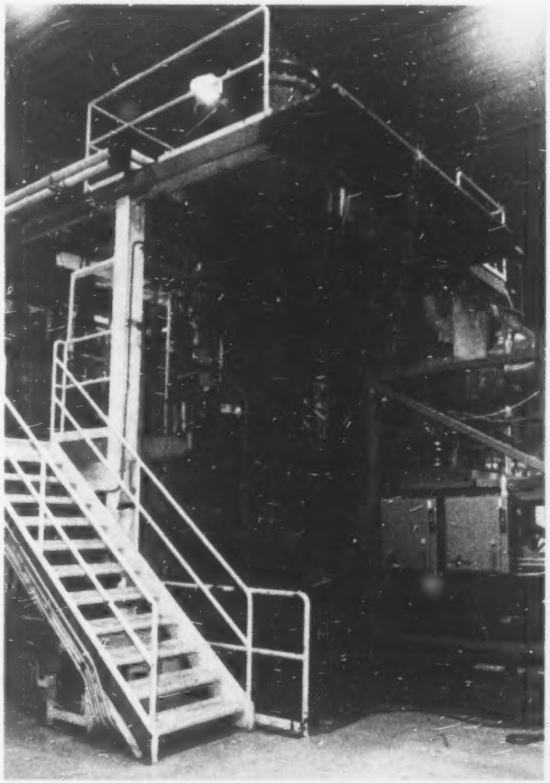

Photo credit: GA Technologies, Inc.

A transportable fluidized bed incinerator that was recently granted a permit for PCB incineration.

OCEAN INCINERATION

Primary statutory authority for regulating ocean incineration resides in the **Marine Protection, Research, and Sanctuaries Act** (MPRSA). Although EPA initially claimed that its jurisdiction under MPRSA did not extend to ocean incineration,[1] the Agency became persuaded of its authority because of rising concern that failure to regulate ocean incineration might frustrate the purposes of MPRSA.

In 1974, ocean incineration without a Federal permit was prohibited. Initial permits were issued using general administrative and technical criteria from the **Ocean Dumping Regulations** (40 CFR 220). Also relied on were the London Dumping Convention's regulations and technical guidelines, including a set of standards for destruction and combustion efficiency, operating conditions, and monitoring parameters (see ch. 12).

The Ocean Dumping Regulations include extensive criteria for use in evaluating permit applications to dispose of waste by ocean dumping. These include criteria for evaluating environmental damages; the need for ocean dumping; and the impact of dumping on esthetic, recreational, and economic values and on other uses of the ocean.

Because the Ocean Dumping Regulations do not specifically address ocean incineration, EPA has recently begun developing an **Ocean Incineration Regulation**. The proposed regulation, which was issued by EPA's Office of Water (50 FR 8222, Feb. 28, 1985), specifies application procedures for research, trial, and operational permits as well as requirements governing incinerator operation, waste specifications, site designation, and operational and environmental monitoring. Specific provisions of the proposed Regulation are discussed throughout this report.

During the public comment period, five public hearings and several public meetings were held around the country. In September 1985, EPA released a summary of the approximately 4,500 comments received during these sessions (1).

Activities of the **London Dumping Convention** (LDC) are germane to domestic policy on ocean incineration, as the United States is a signatory to the convention. All U.S. regulations regarding ocean dumping and ocean incineration must be consistent with those of the LDC, and MPRSA serves as the primary statutory instrument for adherence to the LDC. (See ch. 12 for more information on the LDC.)

Amendments to MPRSA also authorize research and monitoring for ocean incineration and for ocean dumping activities in general, to be carried out by EPA, the National Oceanic and Atmospheric Administration, and the U.S. Coast Guard.

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[1] The basis of EPA's quandary was whether Congress intended MPRSA to cover air pollutants emitted at sea.

STATUTES GOVERNING RELATED ACTIVITIES

For wastes managed using ocean or land-based incineration, the incineration process itself is the last step, except for disposal of incineration residuals, in the "cradle-to-grave" management of hazardous wastes. For operations on land and at sea, various Federal authorities are involved at different stages. Table 25 summarizes the statutes, agencies, and jurisdictions for all incineration support activities.

Various responsibilities also fall on State and local jurisdictions. These include hazardous waste facility siting, enforcement authority, and emergency response.

Designating Ocean Incineration Sites

The proposed Ocean Incineration Regulation contains detailed procedures for the formal designation of sites for ocean incineration (50 FR 8271, Feb. 28, 1985). EPA proposes using the same site-selection criteria for ocean incineration as those specified in the Ocean Dumping Regulations, with three additions:

1. the effect of incinerator emissions on **endangered species** in or near the site must be examined;
2. the site's **carrying capacity** must be calcu-

lated and any requirements that are necessary to ensure that it is not exceeded must be incorporated into individual permits; and

3. a plan to monitor the **environmental effects** of emissions must be developed for each site.

Before formally proposing an incineration site for designation, EPA would prepare an environmental assessment of the use of the site for inclusion in an Environmental Impact Statement where required by EPA policy. As part of this assessment, the carrying capacity and loading rates at the site would be calculated for acid emissions, 14 metals, and the most prevalent organic compounds expected to be incinerated.

Although burns occurring under research or emergency permits could occur at undesignated sites, burns occurring under operational permits could only occur in sites designated through the formal rulemaking process. Use of designated sites would be regulated on a permit-by-permit basis, with respect to carrying capacity, and through evaluation of data obtained from the mandatory environmental monitoring plan specified for each site.

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History of U.S. Ocean Incineration

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Chapter 11

History of U.S. Ocean Incineration

This chapter discusses several facets of the history of ocean incineration in the United States. Past burns, the designation of sites for ocean incineration, and recent Environmental Protection Agency (EPA) activities, including the recently denied proposal for a PCB research burn, are discussed.

PAST BURNS

Four sets of research or interim burns occurred under EPA's authority between 1974 and 1982. All four used the *Vulcanus I* and included varying degrees of monitoring and analysis of stack emissions and the marine environment. In addition, EPA monitored a test of the *Vulcanus II* in the North Sea in 1983. This section describes each of these burns and discusses the reported results. Table 26 presents a summary of these five sets of burns, indicating locations, types of waste incinerated, destruction efficiencies, and other reported results. In each case, a primary reference is indicated for additional information.

Shell Chemical Organochlorine Wastes in the Gulf of Mexico: First Series

Use of ocean incineration was first proposed in the United States in 1974, when Shell Chemical Co. sought permission to use the Dutch-owned vessel *Vulcanus I* to incinerate liquid organochlorine wastes. This type of waste had previously been dumped in the Gulf of Mexico, until EPA halted the practice in 1973. The waste proposed for incineration was a mixture of chlorinated hydrocarbons derived from production of vinyl chloride and other chemicals. The chlorine content of the waste was 63 percent.

In October 1974, EPA granted Shell a research permit to incinerate one shipload (4,200 metric tons, or mt) of the waste at a site 190 miles from land in the Gulf of Mexico. Because several problems arose during the monitoring of this burn, a second research permit for another shipload was granted, and a second burn took place in December 1974. The generally favorable results led EPA to grant a special interim permit for the incineration of two remaining shiploads of waste, which were burned in late December 1974 and early January 1975.

EPA reported that destruction efficiencies for this set of burns averaged 99.95 percent, measured on the basis of total organic carbon. No separate measurement of individual principal organic hazardous constituents (POHCs) or products of incomplete combustion (PICs) was undertaken. Seawater samples taken from the area of contact between the incinerator plume and the ocean surface were analyzed for organochlorines, pH, chlorine content, and trace metals. EPA was unable to detect any changes over background levels.

Shell Chemical Organochlorine Wastes in the Gulf of Mexico: Second Series

In 1977, Shell obtained a special permit to conduct another set of burns in the Gulf of Mexico, and again used the *Vulcanus I* to incinerate four shiploads, or about 16,000 mt, of organochlorine wastes. EPA conducted extensive testing of the first of these burns. Trace amounts of known waste constituents (POHCs) were detected in the stack gas samples; these measurements were used to calculate the POHC-specific destruction efficiencies reported in table 26. The analysis of emissions found very low amounts of other compounds, which had not been identified in the waste, and which may have been PICs.

EPA reported that the DE for total hydrocarbons ranged from 99.991 to 99.997 percent. The DE for the major waste constituent, trichloropropane, ranged from 99.92 to 99.98 percent.

The environmental monitoring of these burns revealed the first evidence of an environmental effect from ocean incineration. Fish in towed cages

Table 26.—Summary of Past Ocean Incineration Burns Monitored by EPA

Date	Vessel	Type of waste	Location	Results reported by EPA[a]	Reference[b]
1974-75	*Vulcanus I*	Organochlorines 63% chlorine Metals ≤1 ppm	Gulf of Mexico	DE 99.92-99.98%, average 99.95%, determined for total organic carbon No detectable emissions in marine water samples No separate sampling for POHCs or PICs	Wastler, et al., 1975 (32)
1977	*Vulcanus I*	Organochlorines 60-70% chlorine Metals 1-200 ppm	Gulf of Mexico	DE 99.991-99.997% for total hydrocarbons 99.92-99.98% for POHC: trichloropropane Possible PICs, <0.01% of waste feed Transient increase in stress-related enzyme in fish exposed to plume No effects observed on plankton	Clausen, et al., 1977 (9) TerEco Corp., unpublished work reported in Kamlet, 1981 (17)
1977	*Vulcanus II*	Herbicide Agent Orange[c] with trace of TCDD (≈2 ppm) 30% chlorine	South Pacific	DE >99.999% for 2,4-D and 2,4,5-T; >99.999% for total chlorinated organics 99.982-99.992% for total organics 99.88->99.99% for TCDD Very limited environmental testing, no effects detected	Ackerman, et al., 1978 (1)
1981-82	*Vulcanus I*	PCBs and chlorobenzenes	Gulf of Mexico	"Inconclusive"	Metzger, et al., 1983 (21)
1982	*Vulcanus I*	PCBs and chlorobenzenes	Gulf of Mexico	DE >99.99989 for PCBs >99.99993 for chlorobenzenes No trace of waste in plume, water samples, or organisms No TCDD (dioxin); possible other PICs at very low level	Ackerman, et al., 1983 (3)
1983	*Vulcanus II*	Organochlorines 84% chlorine	North Sea	DE from 99.998% for chloroform (lowest) to >99.99995% for trichloroethane (highest)	Ackerman, et al., 1983 (4)

[a] The symbol ">" in front of reported DEs indicates that the compound was not detected in emissions, and the actual DE is greater than that listed.

[b] See reference list at end of chapter.

[c] This waste was composed of the n-butyl esters of 2,4-dichlorophenoxyacetic acid (2,4-D) and 2,4,5-trichlorophenoxyacetic acid (2,4,5-T). Trace quantities of 2,3,7,8-tetrachlorodibenzo-p-dioxin (TCDD) were found, ranging from 0 to 47 ppm in various samples.

SOURCE: Office of Technology Assessment.

were exposed to surface water in the area of contact between the incineration plume and the ocean surface. Assays were then conducted on three enzyme systems that increase in activity in response to physiological stress induced by the presence of pollutants. One enzyme system (Cytochrome P-450) showed a significant increase in activity.

When the exposed fish were placed in clean water for several days in the laboratory, the activities of all three systems were found to be normal. Although EPA interpreted the temporary nature of the effect optimistically, detection of such an effect illustrates the need for caution and further monitoring and research of ocean incineration activities. This would be particularly important if incineration at particular sites became frequent or routine, because longer term exposures to marine organisms might result.

Agent Orange Wastes in the South Pacific

Another set of burns employing the *Vulcanus I* occurred later in 1977, in the South Pacific about 120 miles west of Johnston Atoll. The waste incinerated was the herbicide Agent Orange, which came from an Air Force stockpile of many separate drums remaining from production that occurred during the Vietnam War. The waste consisted of roughly equal amounts of 2,4-D and 2,4,5-T (see table 26 for full chemical names), contaminated with the highly toxic dioxin TCDD at a level that ranged from 0 to 47 milligrams per kilogram (mg/kg) and averaged 1.9 mg/kg. Total chlorine content was about 30 percent.

A total of about 10,400 mt of Agent Orange was incinerated in three separate burns. An initial burn of 3,520 mt took place under an EPA research permit. Favorable monitoring results led EPA to authorize incineration of the remaining stock, about 6,880 mt in two shiploads, under a special permit.

Destruction efficiencies were reported in several forms by EPA. For all three burns, the DE for the two main components of Agent Orange, 2,4-D and 2,4,5-T, and for total chlorinated hydrocarbons, exceeded 99.999 percent. In fact, none of these substances was detected at all in the emissions. The *minimum* DE of 99.999 percent was reported, even though the actual DE might have been higher, because the detection limits of the sampling and analytical instruments employed did not allow measurement of a higher DE. Destruction efficiencies for total hydrocarbons ranged from 99.982 percent to 99.992 percent.

Emissions were also analyzed for the presence of TCDD (dioxin), which was found only in samples from the second trial; its detection in these samples may have been caused, however, by interference from other substances. Because TCDD was below the limit of detection in burns 1 and 3, the reported DEs again represent minimum values: 99.99 percent for burn 1 and 99.96 percent for burn 3. A DE of 99.88 percent was calculated for the second burn.

Only limited environmental monitoring was conducted during the Agent Orange burn. Plankton samples at the site collected before and after the first burn showed no consistent differences in numbers or species composition. No other tests were performed on marine organisms.

PCB Wastes in the Gulf of Mexico

An additional set of burns occurred in the Gulf of Mexico, beginning in late 1981/early 1982 and completed later in 1982. Both sets of burns were carried out under research permits. In the first burn, about 3,500 mt of PCB-containing waste was incinerated aboard the *Vulcanus I* (which by then had been acquired by Chemical Waste Management, Inc., of Oakbrook, Illinois). EPA monitored the burn, but later indicated that the data collected were "inconclusive" because of major problems with sampling and analysis. This test in particular is cited by critics of ocean incineration as evidence of the unreliability, if not total unacceptability, of incineration at sea.

The *Vulcanus I* was also used for a second burn of about 3,500 mt of PCB wastes conducted in August 1982. The waste composition included 27.5 percent PCBs, 7 percent chlorobenzenes, and trace amounts (estimated at 0.0000048 percent) of highly toxic tetrachlorodibenzofurans (TCDF). None of the emissions samples analyzed showed any trace of these components, which means that the reported DEs again represent minimum values. These DEs are as follows:

- PCBs............. >99.99989 percent

- Chlorobenzenes .... >99.99993 percent
- TCDF .... >99.96 percent.

Both waste and emissions were analyzed for the presence of TCDD, none of which was detected in any samples. The plume itself was also sampled for PCBs and other organochlorine compounds, and none was detected. However, some nonchlorinated compounds were detected in the plume, and EPA suggested that they either were PICs or arose from the vessel's propulsion engines.

Marine sampling and monitoring was conducted during the second burn, and no detectable increase in PCBs was found in water samples or organisms. Nor did any physiological indicators of exposure-related stress exceed normal levels.

Organochlorine Wastes in the North Sea Using the Vulcanus II

With EPA in attendance, the newly built *Vulcanus II* was tested in February 1983, burning waste from vinyl chloride production at the designated incineration site in the North Sea. The waste consisted almost entirely of four compounds: trichloroethane (39 percent), chloroform (26 percent), carbon tetrachloride (20 percent), and dichloroethanes (15 percent). The waste's total chlorine content was 84 percent; in addition, two of the waste's components (chloroform and carbon tetrachloride) are ranked by EPA as among the most difficult compounds to destroy thermally, because of their high chlorine content. Thus, this waste provided an unusually difficult test of the incinerator.

The reported DEs were high, ranging from 99.998 percent for carbon tetrachloride to more than 99.999995 percent for trichloroethane.

Canceled Burns

In October 1983, EPA proposed issuing two 3-year special permits and one 6-month research permit to Chemical Waste Management, Inc., to incinerate 300,000 mt of PCB-containing waste and 900 m³ of DDT-containing waste in the Gulf of Mexico. EPA based its tentative approval on the successful 1982 PCB burn (using *Vulcanus I*) and the 1983 European organochlorine burn (using *Vulcanus II*).

Major public opposition mounted, culminating in a public hearing in Brownsville, Texas, on November 21, 1983, attended by more than 6,400 people, the largest public hearing in EPA history. In May 1984, EPA denied the permits and announced that no further *operating* permits would be issued until the Agency had promulgated specific ocean incineration regulations and completed several ongoing studies.

In December 1985, EPA published its tentative determination to issue a *research* permit to Chemical Waste Management, Inc., for incineration at sea using the *Vulcanus II* (50 FR 51360, Dec. 16, 1985). EPA initially solicited the research permit as part of its Ocean Incineration Research Strategy (26).[1] The permit would have authorized the incineration of one shipload (about 700,000 gallons) of a waste consisting of 10 to 30 percent PCBs in fuel oil. The waste was to have been loaded at the Port of Philadelphia, transported through Delaware Bay, and incinerated at the North Atlantic Incineration Site. In its application, Chemical Waste Management indicated that the waste it planned to burn would actually contain 12 percent PCBs, and would be transported by rail from its storage facility in Emelle, Alabama (8).

The Coastal Zone Management Act, which is administered at the Federal level by the National Oceanic and Atmospheric Administration (NOAA), grants States the right to review Federal activities affecting their coastal zones for consistency with State management plans. As part of its application procedure, Chemical Waste Management, Inc. sought coastal zone management (CZM) consistency determinations from three coastal States: Delaware, New Jersey, and Pennsylvania. These States were consulted because the *Vulcanus II* would pass through their coastal waters en route to the incineration site. Pennsylvania granted approval without conditions for the single research burn. Delaware also reached a determination of CZM consistency but limited transit to daylight hours and required prior notification of the ship's movement (13). In addition, Delaware was considering suing EPA to require the agency to prepare a separate Environmental Impact Statement on the transit route (13).

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[1] EPA received a separate application from At-Sea Incineration, Inc. (ASI), for the *Apollo I*. However, ASI's parent company, Tacoma Boat, filed Chapter 11 bankruptcy proceedings in the fall of 1985. This move, brought on partly by delays in the finalization of EPA's regulations, forced ASI to default on $68 million in guaranteed loans granted earlier by the U.S. Maritime Administration for construction of its two incineration vessels (14). The loan was paid in full by the Maritime Administration. The uncertain financial status of ASI led EPA to hold its permit application in abeyance pending resolution of the situation (50 FR 51361, Dec. 16, 1985).

New Jersey originally placed several conditions on its finding of CZM consistency. These included prohibiting transit during the summer, extending the moving safety zone, modifying Coast Guard contingency plans for managing a spill, allowing 60 days for the State to verify waste composition, and requiring State approval of the level of liability coverage. In the course of litigation, however, New Jersey withdrew its conditions regarding the moving safety zone and contingency plans, and modified its waste analysis requirement.

In early 1986, the State of Maryland appealed to NOAA for the right to make a CZM consistency determination, claiming that the proposed test burn could adversely affect the State's coastal zone. Maryland argued that, although the vessel would not pass through Maryland waters, those waters could nevertheless be adversely affected by the activity. In February, NOAA ruled in favor of Maryland, despite strong opposition from EPA. Maryland was granted 6 months to conduct its review and reach a consistency determination (letter cited in ref. 11).

In response to the NOAA decision and the strict conditions imposed by New Jersey, Chemical Waste Management filed suit in March against NOAA and EPA (15). The suit contended that Maryland was not entitled to conduct a consistency review for an activity that would occur outside of its coastal zone. In addition, Chemical Waste Management contended that the Marine Protection, Research, and Sanctuaries Act preempts New Jersey from imposing conditions.

Prior to any decision in the suit, the State of Maryland and Chemical Waste Management reached a settlement in which Maryland withdrew its request to conduct a CZM consistency review of this research permit but retained its right to pursue such a review in the future (16).

Following the announcement of its tentative determination to grant a research permit to Chemical Waste Management, EPA held a series of public hearings in Philadelphia; Red Bank, New Jersey; Wilmington, Delaware; and Ocean City, Maryland. Through the course of these hearings, strong public opposition again surfaced, focusing particularly on the land and nearshore marine transportation risks. These concerns led to the issuance of a Hearing Officer's report (31) that called for the resolution of several major issues of public concern before proceeding with the burn.

In May 1986, EPA announced its decision to deny the research permit, and to grant no permits, research or otherwise, until finalization of its Ocean Incineration Regulation (51 FR 20344, June 4, 1986). In its decision, EPA argued that the nature of the issues raised in considering the research permit could be more appropriately addressed through the regulatory development process.[2]

As a result of EPA's decision, the suit brought by Chemical Waste Management was dismissed without a ruling on the circumstances under which permit applicants are required to demonstrate CZM consistency or the rights of States to place conditions on their finding of CZM consistency (11).

ADEQUACY OF PAST BURNS IN DEMONSTRATING THE SAFETY OF OCEAN INCINERATION

All of the burns discussed above took place under EPA regulations that incorporated the technical requirement of the London Dumping Convention mandating a minimum destruction efficiency of only 99.9 percent. Therefore, all but one of the reported DEs met the required standard. (The exception was the reported DE for TCDD in the second burn of Agent Orange, which appears to have been anomalous and may have resulted from interference by chemically related compounds.)

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[2] The PCB wastes that were to have been incinerated under the research permit are now expected to be transported to Chicago for incineration in Chemical Waste Management's land-based incinerator.

In 1981, EPA adopted rules requiring land-based hazardous waste incinerators to achieve a 99.99 percent DE. In addition, the Toxic Substances Control Act requires a minimum 99.9999 percent DE for PCBs. EPA has proposed that the same values be adopted in the regulations governing ocean incineration. The ability of ocean incineration to achieve this DE has not yet been demonstrated. Past test burn data for PCBs was derived from analysis of samples that were not large enough to definitively establish that the *Vulcanus I* is capable of meeting a 99.9999 percent DE. However, EPA believes that this DE was achieved in the burn and is achievable using ocean incineration (28).

No consensus exists with regard to the adequacy and accuracy of EPA's past efforts to monitor ocean incineration. Based on its monitoring of incinerator performance and the environment during past ocean incineration activities, EPA reported that it had been unable to detect any increase in background levels of waste constituents in ambient air, water, or marine organisms. Many members of the public and EPA's own Science Advisory Board (SAB), however, have expressed concerns about these conclusions and the methods and adequacy of EPA's monitoring efforts. (For further critical discussion of these past efforts, see refs. 6,7,18, 19,29).

In response to these concerns, EPA has called for additional test burns before operating permits are issued. The test burns would be intended to provide more accurate assessments of the performance, levels of emissions, and environmental consequences of ocean incineration. In addition, the proposed regulations governing ocean incineration contain provisions for comprehensive environmental monitoring, which would be conducted by EPA with the participation of permittees.

Past Incidents

Several small spills and contamination of the vessel occurred during three of the sets of burns described in this chapter.

During the incineration of Agent Orange in the Pacific (1), several small spills of herbicide occurred, caused by accidental breakage of a sampling bottle; sloshing of liquid through a tank hatch, as a result of rough seas; and overfilling of a tank during rinsing. One or more of these spills was apparently tracked by personnel, leading to the contamination of other areas of the vessel. This contamination was detected during routine monitoring of the vessel performed as a precautionary measure.

There have also been reports of a more serious release of waste from this burn, caused by the intentional discharge of bilge water, which was apparently contaminated with Agent Orange, into a lagoon at Johnston Atoll (12,22). Sampling of lagoon water in the immediate vicinity of the bilge water discharges revealed concentrations of herbicide that significantly exceeded water quality criteria. Reported concentrations were as high as 3 to 5 parts per million, and the total release of herbicide was estimated to have been about 270 pounds (12). In addition, a visible orange cloud in the water was noted, although the captain of the *Vulcanus I* maintained that the color was caused, not by herbicide, but by rust (22).

Several small spills on deck were reported during the first of the PCB burns that took place in the Gulf of Mexico in 1981-82 (2,25). Some contamination of other parts of the vessel (the burner room, pumproom, and a gangway) was also reported, identified during routine monitoring of the vessel.

During the Agent Orange burns (1) and the 1977 organochlorine burns in the Gulf of Mexico (9), several "impingements" of the incinerator plume onto the deck of the vessel were reported. These were attributable to momentary flameouts caused by water in the waste being incinerated or to high wind velocities and erratic wind direction, and in some cases resulted in brief exposure of crew members to emissions. Based on consideration of the circumstances surrounding these incidents, steps were taken to avoid or reduce their subsequent occurrence.

Several other incidents have been reported or alleged to have occurred during ocean burns that occurred in Europe. These are discussed in reference 20.

Certain provisions of EPA's proposed Ocean Incineration Regulation directly address these types of incidents. In particular, bilge and ballast waters and tank washings would have to be tested for the presence of waste constituents and, if contaminated, either incinerated at sea or disposed of in an approved land-based facility (50 FR 8236, Feb. 28, 1985). In addition, the vessel would at all times be required to maintain a course and speed which, in combination with the prevailing wind speed, would yield a combined effective wind speed over the vessel of 3 knots or more, to ensure that the plume remained aft of the vessel and would not come into contact with the crew (50 FR 8251, Feb. 28, 1985).

SITE DESIGNATION

Under the Marine Protection, Research, and Sanctuaries Act, incineration sites must be designated by EPA, and operational permits for ocean incineration may only be granted for designated sites. The site designation process falls under formal rulemaking procedural requirements mandating public hearings. In addition, an Environmental Impact Statement (EIS) must be prepared for each site.

The following discussion highlights the status of designation activities for ocean incineration sites.

Gulf Site

Currently, only one site has been designated for ocean incineration. The final EIS for the Gulf of Mexico Incineration Site was issued in 1976 (23). This site lies in the middle of the Gulf, about 190 miles from land, and occupies an area of 4,900 square kilometers (see figure 12). The site is beyond the edge of the continental shelf, in waters ranging in depth from 1,000 to 2,000 meters (5).

The Gulf Site was initially designated in 1976 (41 FR 39319, Sep. 15, 1976) and redesignated in 1982 (47 FR 17817, Apr. 26, 1982). The 1982 rule designated the Gulf Site for "continued use." The proposed Ocean Incineration Regulation would limit designation of the Gulf Site to a period of 10 years, assuming that the additional proposed requirements for site designation were met (see ch. 10). Some members of the public and elected officials have called for the designation process for the Gulf Site to be reopened, based on new information and developments since 1976 (see ch. 2).

North Atlantic Site

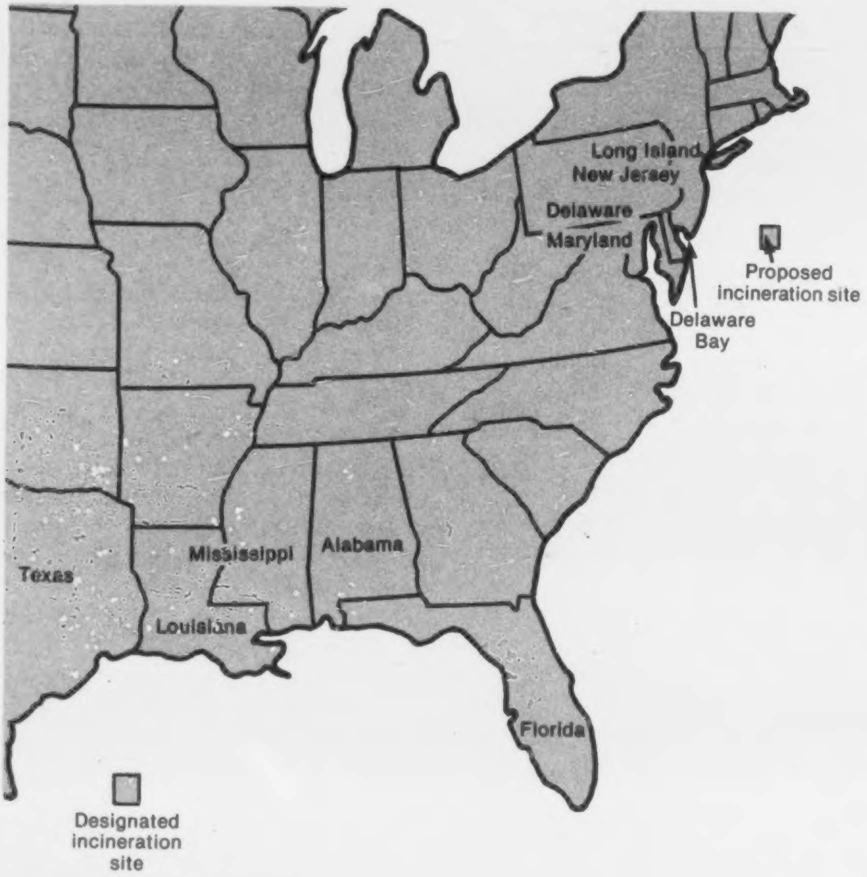
In 1981, a final EIS for the North Atlantic Incineration Site was released (24). This site, which has not been formally designated, lies about 140 miles east of the coasts of Delaware and Maryland and covers 4,250 square kilometers (see figure 12). The site lies beyond the continental shelf on the continental rise, in waters ranging in depth from 2,400 to 2,900 meters. Due north and adjacent to the proposed incineration site is the 106-mile Ocean Waste Disposal Site, which is expected to be used for dumping industrial acid and alkaline wastes as well as municipal sludge for the foreseeable future.

Since the development of the 1981 EIS, the National Marine Fisheries Service (NMFS) has found that the proposed North Atlantic Incineration Site lies in a "high use" area for several species of endangered or threatened marine mammals (see ch. 9). In response to this finding, EPA reevaluated the site and concluded that endangered species would not be affected by incineration there (30). NMFS has concurred with this conclusion with respect to limited use of the site for research burns. However, NMFS must develop a formal biological opinion for consideration prior to EPA's final designation of the site.

Other Possible Sites

EPA-sponsored studies have tentatively examined areas off the coasts of California and Florida as possible future sites for ocean incineration. However, no steps in the actual site designation process have taken place to date.

Figure 12.—Location of the Designated (Gulf of Mexico) and Proposed (North Atlantic) Incineration Sites


Long Island
New Jersey
Delaware
Maryland
Proposed incineration site
Delaware Bay
Texas
Mississippi
Alabama
Louisiana
Florida
Designated incineration site

SOURCE: Office of Technology Assessment.

RECENT EPA EFFORTS

In conjunction with the development and issuance of its proposed Ocean Incineration Regulation, EPA sponsored several studies.

Science Advisory Board (SAB) Study

In April 1985, EPA's SAB released its "Report on the Incineration of Liquid Hazardous Wastes by the Environmental Effects, Transport, and Fate Committee" (29). The report examined various scientific issues bearing on incineration's impacts on human and environmental health and compared and contrasted the current level of understanding of land-based and ocean incineration technologies.

Although stating that "incineration is a valuable and potentially safe means for disposing of hazardous chemicals," and that the report's intent was to "strengthen already existing incineration programs rather than to discontinue what is already in place," the SAB identified several major areas where existing data are insufficient. In particular, the SAB found that no reliable characterization of incinerator emissions or their toxicities was available, which meant that the potential for environmental or human exposure and impact could not be assessed. The study challenged EPA's measurement of destruction efficiency, which addresses only a few selected compounds, as a basis for evaluating the total performance of incinerators. It recommended that EPA undertake a complete characterization of emissions, including products of incomplete combustion (PICs).

The report stressed that the uncertainties the SAB had identified applied equally to land-based and ocean incineration and, in many cases, to other common combustion processes, such as the burning of fossil fuels. The report also argued that, because it destroys waste, incineration is preferable to current methods of disposal, such as landfilling and deep-well injection.

Incineration Study

EPA's Office of Policy, Planning and Evaluation (OPPE) (27) published an "Assessment of Incineration as a Treatment Method for Liquid Organic Hazardous Wastes" in March 1985. The study compared and evaluated land-based and ocean incineration with respect to technology, regulation, commercial market potential, relative environmental and health risks, and public concerns. The major conclusions are the following:

- incineration, whether at sea or on land, is a valuable and environmentally sound treatment option for destroying liquid hazardous wastes, particularly when compared to land disposal options now available;
- there is no clear preference for land-based or ocean incineration in terms of risks to human health and the environment; and
- future demand for hazardous waste incineration will significantly exceed capacity as other disposal alternatives are increasingly restricted.

Ocean Incineration Research Strategy

EPA's Office of Water published an Ocean Incineration Research Strategy (26) detailing the means by which EPA intends to address the areas of uncertainty identified in the SAB and OPPE reports, in previous research burns, and in comments received from the public. The strategy calls for several research burns, both on land and at sea. Initial dockside burns with diesel fuel would allow development and testing of methodology; subsequent burns of hazardous waste would be designed to gather data on incinerator performance, the quantity and composition of emissions, and environmental effects.

Proposed Research Burn

As described earlier in this chapter, EPA proposed to issue a research permit for incineration at sea as part of its research strategy (50 FR 51360, Dec. 16, 1985). The burn was planned to be continuous for 19 days, during which EPA would conduct extensive sampling and monitoring of all aspects of operation. The following specific tests were planned:

- determination of flow characteristics and combustion efficiency at all points in the stack;
- sampling and analysis of emissions to allow measurement of: 1) semi-volatile trace organic compounds, including PCBs, for calculation of destruction efficiency; 2) volatile organic compounds; 3) particulates; and 4) total chlorinated organic compounds;
- collection of samples for toxicity testing;
- actual toxicity bioassays on five marine plant and animal species, testing for acute toxic effects and chronic effects on growth and reproduction;
- plume sampling and modeling; and
- collection and analysis of samples of air, water, and indigenous organisms for determining the presence of, or effects from, incineration-derived substances.

The Usefulness of Research Burns: Opportunities and Limitations

Recent EPA developments are likely to considerably delay issuance of the final Ocean Incineration Regulation and any subsequent research burns. Clearly, ocean research burns are necessary to resolve *some* of the technical questions about ocean incineration. In addition, if a decision were made to proceed with ocean incineration, information from research burns could aid in modifying the regulatory program, if necessary.

Nonetheless, there are limits to the usefulness of the data that could be obtained from ocean research burns. Foremost among these is the fact that the data would *not* resolve the basic issue of whether to proceed with the ocean incineration program. Technical analysis is only one of many factors influencing such a decision.

Moreover, one or even a series of research burns would still leave many technical questions unresolved. For example, the recently denied EPA research burn would have used a waste composed of relatively homogeneous PCBs in fuel oil (8). This waste was chosen because toxicity characteristics and detection methods for PCBs are well studied, and because EPA wanted to have as little interference from other chemicals as possible. Typical ocean incineration wastestreams, however, would be more likely to contain complex mixtures of many chemicals, which limits the applicability of results from this test burn to "real" situations. Conversely, choosing a heterogeneous wastestream for the research burn would have introduced a different but comparable set of constraints.

Finally, to be most useful, ocean incineration research must be coupled to research on other alternatives. A proper comparative analysis would require research on both land-based and ocean technologies. EPA does have an ongoing research program on land-based incineration, and EPA's ocean incineration research strategy contains a land-based incinerator component—primarily to allow testing of the protocols for sampling, analysis, and toxicity tests to be used during an ocean research burn.

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The Regulation and Use of Ocean Incineration by Other Nations

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Chapter 12

The Regulation and Use of Ocean Incineration by Other Nations

This chapter provides overviews of the past, present, and future use of ocean incineration by nations other than the United States. The first section provides a brief history of international use and regulation of ocean incineration. The second section discusses the various international and regional conventions and other deliberative bodies that have addressed the use of ocean incineration and describes several important recent actions. The third section presents a summary of data on the past and present use of ocean incineration by other nations. The fourth and final section briefly discusses the policies and practices of 11 individual nations, based on information from several sources, including a survey of foreign embassies conducted by OTA.

HISTORICAL BACKGROUND

Commercial use of ocean incineration by other nations dates back to 1969, when the first incineration vessel, a modified chemical tanker named *Matthias I,* was launched under the flag of the Federal Republic of Germany. Development of ocean incineration for the purpose of incinerating organochlorine wastes was initially motivated by five factors (12):

1. the many problems encountered on land in operating and maintaining scrubbers in the presence of the corrosive gases produced by incinerating organochlorine wastes;
2. the ability of seawater to neutralize the gases, thereby negating the need for scrubbers;
3. additional problems arising from treating and disposing scrubbing effluents and sludges;
4. the advantage of a centralized, large-scale system for collecting and incinerating organohalogen wastes, which could potentially be better controlled and monitored, as well as more economical, than other alternatives; and
5. unacceptable impacts from ocean *dumping* of certain organochlorine wastes, such as tars arising from the production of ethylene dichloride.

Consideration of these factors led to an increase in the European market for ocean incineration and the launching of two additional ships, the *Matthias II* and the *Vulcanus I,* in the early 1970s. All three ships operated exclusively in the North Sea.

Also at this time, international concern was increasing over environmental impacts of ocean disposal of wastes in general. These concerns led to the development of the worldwide London Dumping Convention (LDC) and the regional Oslo Convention, both established in 1972. Although these conventions did not initially address ocean incineration, proposals to begin incineration in the Mediterranean Sea prompted two developments. First, the Barcelona Convention, established in 1976, decided to prohibit incineration in the Mediterranean Sea (12). Second, the LDC and the Oslo Commission began developing special provisions and codes of practice to govern the use of incineration at sea. Groups of experts convened by both conventions developed sets of technical guidelines for incorporation into the conventions. The guidelines covered the following topics:

- control and approval of incinerator system design and specifications,
- control over the nature of wastes to be incinerated at sea,
- criteria for the selection of incineration sites,
- control over vessel design and operation,
- requirements for monitoring and the use of recording devices, and
- reporting requirements and procedures for incineration activities.

The next section examines the approaches and recent activities of these and other international bodies with regard to ocean incineration.

INTERNATIONAL BODIES

London Dumping Convention

The LDC considers incineration at sea as legally constituting ocean dumping and has developed extensive procedural and operational requirements, which are contained in Annexes to the Convention (8). Under the LDC, incineration at sea is viewed as an *interim* method of waste management, as reflected in LDC Regulation 2.2:

> Contracting parties shall first consider the practical availability of alternative land-based methods of treatment, disposal or elimination, or of treatment to render the wastes or other matter less harmful, before issuing a permit for incineration at sea in accordance with these Regulations. Incineration at sea shall in no way be interpreted as discouraging progress towards environmentally better solutions including the development of new techniques.

At a meeting of the LDC's Scientific Group on Dumping (SGD) in 1985, a working group on ocean incineration was convened to identify and discuss several unresolved questions regarding the performance of and monitoring capabilities for incineration at sea (7). These issues include the following:

- the relationship between destruction and combustion efficiencies over a broad range of operating conditions;
- the ability to sample incinerator stack gases in a mannner that is representative of the entire emission;
- the ability to accurately sample particulate matter in stack emissions; and
- the nature and significance of newly synthesized compounds (products of incomplete combustion, or PICs) in stack emissions.

A group of experts jointly drawn from the LDC and the Oslo Commission is to undertake further discussion of these issues at an intersessional meeting in 1986 or 1987. This discussion was to be based in part on new information provided by the U.S. PCB research burn (10); given its cancellation, the timing of formal international consideration of these questions is not clear.

The International Maritime Organization (IMO) is designated under the LDC to serve as Secretariat. The IMO, therefore, is responsible for collecting data from Contracting Parties on ocean incineration activities, including the number and status of permits, as well as the quantities and types of wastes authorized for incineration at sea. The most recent of these data (for activities in 1982) are discussed later in this chapter.

Oslo Commission

Rule 2.3 of the Oslo Commission Rules, adopted in 1981, stipulates that "the Commission will meet before the 1st of January 1990 to establish a final date for the termination of incineration at sea" in the North Sea, which comprises the Oslo Convention area (15). The 1990 date was formulated at a time when few controls existed over the use of ocean incineration. Since that time, international (LDC and Oslo Commission) and national regulations have been developed to cover most aspects of this technology, leading some Oslo Commission nations to see the need to terminate use of ocean incineration in the near future as less pressing; other members, however, remain committed to its termination by 1990 (see profiles of individual nations later in this chapter).

At the Commission's 11th meeting, held June 11-13, 1985, The Netherlands presented the results of a survey of member nations, which was undertaken to gauge the availability of alternative means of disposing wastes currently incinerated at sea (17). The survey provided an initial step toward assessing the practicality of fulfilling the language of Rule 2.3. Responses to The Netherlands survey were received from all but two members (France and Spain). Its conclusions are as follows:

- There is a potential shortfall in the capacity of land-based incinerators and other land-based treatment methods to dispose of the wastes currently being incinerated at sea.
- Spare capacity on land is considered far from sufficient to match the wastes currently being

incinerated at sea, and very little increase in such capacity is expected in the near future.

- It is expected that by 1990 wastes will remain for incineration at sea.

In 1987, at its 13th meeting, the Oslo Commission expects to draft a policy statement on the termination of incineration at sea, contingent on the availability of adequate capacity in acceptable land-based alternatives (16).

The Commission's Standing Advisory Committee for Scientific Advice (SACSA) examined data regarding the location of the current North Sea incineration site, and concluded that "there is no better compromise between meteorological and logistical requirements (shorter approach to the incineration site resulting in higher cargo safety)." This finding was endorsed by the commission at its 11th meeting in 1985 (16).

Commission of the European Communities

This commission exists under the auspices of the European Economic Community (EEC). In July 1985, the commission submitted to its Council of Ministers a proposal for a council directive on the dumping of waste at sea (2). Ocean incineration is explicitly included in the definition of "dumping at sea." The intent of the directive would be to reduce and terminate all dumping at sea by EEC Member States as soon as possible. Under the directive, ocean incineration would be regarded as a "temporary" disposal option to be used "only if there are no practical alternative methods of land-based treatment," as determined on a case-by-case basis.

EEC Member States would be required to submit to the commission by January 1, 1990, information required for setting a final date for terminating incineration at sea. The council would be required to act on the information within 6 months of that date.

If adopted, the directive would prohibit the granting of any new special permits for incineration after January 1, 1988. Permits already in effect could be renewed until January 1, 1990, for up to 5 years, but Member States would be required to decrease the quantities of waste incinerated at sea each year by 10 percent.

European Parliament

The European Parliament also exists under the auspices of the EEC. A Parliament report (4) issued by the Committee on the Environment, Public Health, and Consumer Protection in December 1983 identified ocean incineration as a contributor to pollution of the North Sea through the release of ash, hydrogen chloride gas, and small quantities of unburned waste to the atmosphere. The report suggested that ocean incineration be relocated to a less sensitive location in the Atlantic Ocean.

USE OF OCEAN INCINERATION BY OTHER NATIONS

This section presents available data on European incineration vessels, the number of voyages they have made, and the quantities and types of European wastes that have been incinerated at sea.

Incineration Vessels

A total of six vessels have been built and employed to incinerate European wastes at sea. Table 27 provides a summary of the most important features of these six vessels, including dates of operation. All but one vessel (the *Vulcanus I*) have operated exclusively in the North Sea. All but the *Matthias III*, which was only used for a brief time, are much smaller than typical tank ships.

Quantities of Waste Incinerated

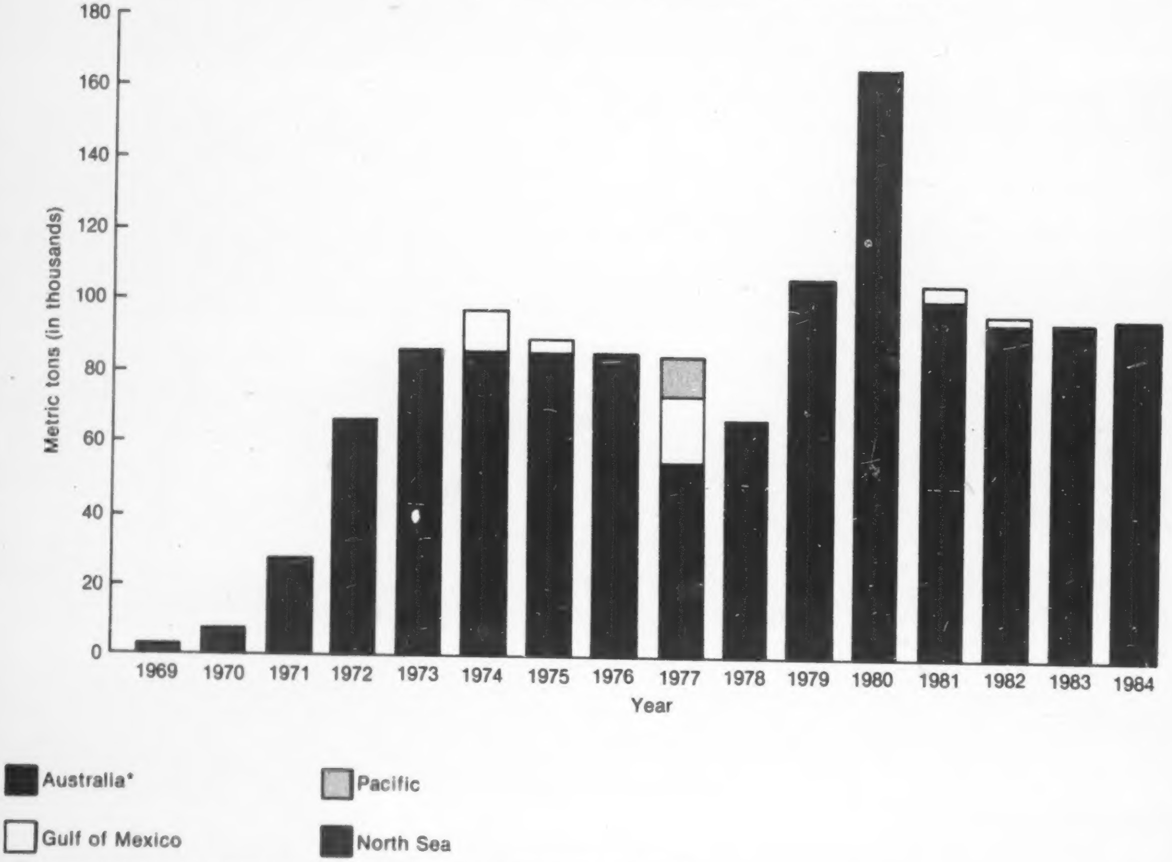
Quantities of wastes managed by ocean incineration steadily increased from 1969, when incineration began in the North Sea, until about 1979, when quantities stabilized at the present level of about 100,000 metric tons annually (fig. 13). The great majority of all waste has been incinerated in

Table 27.—Incineration Vessels Employed in Europe, 1969 to Present

	Matthias I	*Matthias II*	*Matthias III*	*Vulcanus I*	*Vulcanus II*	*Vesta*
Dates of service	1968-76	1970-83	1975-77	1972-present	1982-present	1979-present
Site of operation	Exclusively in the North Sea			North Sea United States Pacific Australia	North Sea	North Sea
Number of incinerators	1	1	1	2	3	1
Total cargo (mt)	550	1,200	15,000	3,500	3,200	1,400
Total gross tons	438	999	12,636	3,100	3,100	999

SOURCE: Office of Technology Assessment based on M.K. Nauke, "Development of International Controls for Incineration At Sea," *Wastes in the Ocean*, vol. 5, D.R. Kester, et al. (eds.) (New York: John Wiley & Sons, 1985), pp. 33-52; and Ocean Combustion Service, *15 Years of Waste Incineration At Sea: History, State of the Art, Control, Environmental Impact* (Rotterdam, The Netherlands: February 1985).

Figure 13.—Quantities of Waste Annually Incinerated At Sea, 1969-84



*This waste was generated in Australia and incinerated while the ship was en route to Singapore.

SOURCE: Ocean Combustion Service, "15 Years of Waste Incineration At Sea: History, State of the Art, Control, Environmental Impact" (Rotterdam, The Netherlands: Ocean Combustion Service, February 1985); M.K. Nauke, "Development of International Controls for Incineration At Sea," in *Wastes in the Ocean*, vol. 5, D.R. Kester, et al. (eds.) (New York: John Wiley & Sons, 1985), pp. 33-52; and International Maritime Organization, "Consideration of Report on Dumping, Draft Report of Permits Issued in 1982," document LDC/SG.8/INF.3, prepared for 8th Meeting of Scientific Group on Dumping (London: Dec. 20, 1984).

the North Sea, but smaller amounts were burned by the *Vulcanus I* in the Gulf of Mexico (Shell wastes and PCBs), in the Pacific Ocean (Agent Orange), and in one burn near Australia. Figure 13 presents the estimated quantities burned between 1969 and 1984.

Many different European countries, as well as Australia and Japan, have used ocean incineration. Each member nation must report annually to the LDC, providing data on the quantities of waste sent for incineration at sea. Table 28 presents the most recent available compilation of such data, covering the year 1982.

These data indicate that 14 LDC nations in addition to the United States incinerated wastes at sea in 1982. Actual quantities sent for incineration varied significantly, ranging from 200 metric tons (Spain) to 53,000 metric tons (Germany). Most wastes are sent for loading at Antwerp, Belgium, although other ports have also been used (e.g., Rotterdam in The Netherlands and Le Havre in France); in addition, permits have been granted for exporting wastes from nations such as Finland. Four vessels were used to incinerate wastes in the North Sea in 1982. Of the 94,000 mt of waste actually incinerated in the North Sea in 1982, the following proportions were incinerated by each vessel: *Matthias II*, 29 percent; *Vulcanus I*, 25 percent; *Vesta*, 42 percent, and the newly commissioned *Vulcanus II*, 4 percent.

Table 28.—Type of Waste Incinerated and Country of Origin, 1982

Country	Type of waste	Quantity[a]
Australia	Vinyl chloride and PCB wastes	4,820
Austria	Organohalogen wastes	490
Belgium	Organohalogen wastes	10,643
Finland	Organohalogen wastes	2,750
France	Organohalogen wastes	6,582
Germany	Organohalogen wastes	52,751
Italy	Organohalogen wastes	3,431
Japan	Oily sludges	1,488
The Netherlands	Organohalogen wastes	9,396
Norway	Organohalogen wastes	8,000
Spain	Organohalogen wastes	210
Sweden	Organohalogen wastes	6,420
Switzerland	Organohalogen wastes	3,711
United Kingdom	Organohalogen and organophosphorous wastes	6,194
Total		116,886[a]

[a] These are quantities for which permits were granted; in some cases, the amount of waste actually incinerated in 1982 was smaller.

SOURCE: International Maritime Organization, "Consideration of Report on Dumping, Draft Report of Permits Issued in 1982," Document LDC/SG.8/INF.3, prepared for 8th Meeting of Scientific Group on Dumping (London: Dec. 20, 1984).

Number of Voyages

EPA formulated estimates of the number of voyages, as well as quantities of waste incinerated, by the two *Vulcanus* ships and the *Vesta* from their launch dates through 1983 (app. C in ref. 19). These data indicate that the ships made 322 voyages and incinerated more than 650,000 mt of waste. Comparable data were not available for the three *Matthias* vessels.

The total number of incineration voyages is likely to be substantially higher, because almost twice as much waste was incinerated at sea by all *six* vessels over the period 1969-84 (see figure 13).

Characteristics of Waste Incinerated

The vast majority of waste incinerated in the North Sea is organochlorine waste. Of the 100,000 mt incinerated in the North Sea in 1981, about 80 percent consisted of organochlorines (6). Many of these wastes have appreciable chlorine content, estimated to average between 60 and 70 percent (11). The waste burned during testing of the *Vulcanus II* in 1983 (see ch. 11) was derived from vinyl chloride production in Norway and had a chlorine content of 84 percent. Chemical Waste Management, Inc., estimated that 65 percent of the waste incinerated by the *Vulcanus* ships in the North Sea had chlorine contents greater than 35 percent (1).

Few data are available characterizing European wastes with respect to metal content; the available analyses, however, indicate that metals are typically in the parts per million range (12). The Oslo Commission (17) has estimated that approximately 90 percent of the emissions of heavy metals from incineration at sea originate from wastes with chlorine content less than 45 percent. Wastes with high metal content (and low chlorine content) are increasingly being diverted to land-based incineration (3).

With respect to emissions of heavy metals, the Oslo Commission (17) estimates that the total contribution of ocean incineration to the Dutch part of the North Sea (encompassing the incineration site) represents less than 0.3 percent of the total input of metals. The German Hydrographic Institute has compared such emissions to the average input of metals entering the North Sea via the Rhine River (cited in ref. 3). The contribution from the Rhine River is estimated to be 1,000 to 10,000 times higher than that from ocean incineration emissions, for each of six toxic metals.

No PCBs have been incinerated at sea in Europe; LDC regulations list PCBs as a waste about which there is doubt regarding its thermal destructability. However, The Netherlands has announced plans to conduct a research burn using PCBs in late 1986 or 1987. The loss of land-based incineration capacity (located in England and France) previously used for PCBs by The Netherlands necessitated reconsideration of the at-sea incineration option (10,18).

PROFILES OF INDIVIDUAL NATIONS

This section describes the policies and practices of 11 individual nations regarding the use of ocean incineration for managing hazardous wastes. All 11 are signatories to the LDC, and all but two (Canada and Denmark) have used ocean incineration.

Sources for the information presented in this section, unless otherwise noted, include *The First Decade*, a report of the Oslo and Paris Conventions published in 1984 (ref. 14), and letters from foreign embassies received in response to an OTA request for information on practices and policies regarding ocean incineration.

Major Conclusions

The data presented below, as well as that contained in the survey of Oslo Commission members described above, provide the basis for two major conclusions regarding the use of ocean incineration by other nations:

1. The major constraint blocking termination of ocean incineration is the lack of sufficient land-based capacity for treating organochlorine wastes.
2. A broad range of opinion and position regarding future use of ocean incineration exists among European nations. For example, the United Kingdom holds a quite favorable view, whereas Denmark argues for termination as soon as possible. Other nations, such as The Netherlands and the Federal Republic of Germany, are attempting to reduce their reliance on ocean incineration but regard it as a necessary option for the foreseeable future due to lack of land-based capacity.

Belgium

Belgium estimates that it generates about 100,000 mt of hazardous waste each year, an unreported fraction of which is incinerated on land. About 10,000 mt of hazardous waste generated in Belgium was incinerated at sea in 1982.

Belgium regards incineration at sea to be "an acceptable solution whenever difficult technical and/or economic problems arise regarding incineration on land." For Belgium, ocean incineration is "a fairly attractive method as the burners and furnaces can be relatively simplified and it is not necessary to provide for the neutralization of the combustion gases due to the buffering capacity of seawater. The method's main drawback is that at sea it is more difficult to efficiently control the effectiveness of the incineration process and the way in which these operations are carried out."

Antwerp, Belgium, has served as the major port for incineration vessels operating in the North Sea. Currently, the loading and transit of incineration vessels occur two or three times each month. Because this activity involves the burning of wastes from numerous European countries, importation and storage of hazardous wastes at Antwerp is routine. For example, in 1982, Antwerp received about 70,000 mt of hazardous waste destined for incineration in the North Sea. This waste originated in seven European nations in addition to Belgium (9).

Belgium's land-based treatment capacity for highly chlorinated wastes is limited to a few private onsite destruction facilities. Thus, chlorinated wastes for which no other alternative exists will continue to be sent for incineration at sea. Belgium has experienced little change in the amount of wastes incinerated at sea over the past decade and anticipates little change for the next 5 years. A new publicly owned incineration plant, scheduled for completion in 1988, should cause some decrease (17).

Canada

Canada views the use of ocean incineration as "one of many options which, if properly controlled, could help in the management of hazardous wastes." Canada anticipates having only small quantities of waste suitable for ocean incineration, has not incinerated any wastes at sea, and has no immediate plans to do so. However, a general application from Chemical Waste Management, Inc., has prompted a further evaluation of the technology, based in large part on a review of relevant LDC data.

Denmark

Denmark is engaged in a substantial hazardous waste management program administered by public authorities, with land-based incineration representing the primary method of treatment or disposal. Of the 40,000 mt of chemical waste received at the central treatment facility (known as Kommunekemi) in 1980, 80 to 90 percent is treated by incineration. Total incineration capacity of the facility is about 90,000 mt annually.

No permits for ocean incineration have been issued by the Danish Minister for the Environment. Although Denmark regards thermal destruction to be a "useful and acceptable disposal method," especially for organohalogen wastes, it believes that "incineration at sea presents great problems in connection with the control of destruction and combustion efficiency." In addition, Denmark expresses concern about the large areas of the North Sea that are unavailable for other uses because of ocean incineration, and concern about the potential for the technology to aggravate regional problems with acid rain.

The Danish Government, which has been the most vocal and consistent opponent of ocean incineration in the European community, continues to press for an end to the practice, particularly in the North Sea.

Finland

Finland estimates that it produced about 500,000 mt of hazardous waste in 1975. The majority of Finland's oily wastes and about half of its solvent wastes are burned, mostly in land-based incinerators. Finland currently lacks sufficient incineration capacity for PCBs and certain other chlorinated wastes, and hence exports these wastes to the United Kingdom for destruction in a land-based incinerator (17).

Finland has recently constructed (at Riihimki) a centralized hazardous waste treatment facility, which has a capacity of 70,000 mt annually. Land-based incineration is the major technology at this facility. It is unclear if and to what extent this will affect the need for Finland to continue to export PCBs and other wastes.

Incineration at sea has twice been used to destroy wastes (a total of 5,250 mt) from one of Finland's petrochemical plants, which is closed at least for the time being. No definitive policy statements by Finland regarding ocean incineration are available.

France

France estimates that it annually generates 18 million mt of hazardous industrial waste, 2 million mt of which are especially toxic or hazardous. In 1982, approximately 200,000 mt of this waste was incinerated at 10 "special collective plants" located throughout France. A comparable quantity was incinerated in onsite facilities operated by various industrial firms. Of the 10 commercial facilities, which have a total annual capacity of 205,000 mt, 4 are equipped to incinerate chlorinated wastes, and 3 can burn only liquid wastes. These facilities compete with 5 cement kilns, which have recently increased their share of the market for wastes with high heat content.

France points to insufficient capacity and the high cost of land-based incineration of organochlorine wastes as factors motivating its use of ocean incineration. Waste to be incinerated in the North Sea is directed to the ports of Le Havre, France, and Antwerp, Belgium, the latter receiving primarily or exclusively wastes with high chlorine content. Waste generators do not have direct access to incineration vessels, which receive waste only from treatment plants. Annual quantities incinerated at sea since 1979 have ranged from 4,600 mt to 11,700 mt, averaging about 10,000 mt.

France anticipates that a gradual increase in land-based incineration capacity and decreases in its cost will reduce the quantities of waste incinerated at sea.

Federal Republic of Germany

The Federal Republic of Germany (FRG) estimates that its annual production of industrial special or toxic waste amounted to about 4.5 million mt in 1980. A total of 17 land-based incineration plants handle an unreported portion of these special wastes.

The FRG has expressed a variety of views on the use of ocean incineration. According to its submission to the Oslo Commission (14), the FRG regards ocean incineration "to be ecologically the soundest of the available methods for the disposal of halogenated hydrocarbons" but not "an ideal disposal method," preferring to develop appropriate reuse and recycling efforts. These methods include land-based thermal destruction technologies that provide for recovery or reuse of chlorine residues released during the process, as well as more conventional heat recovery.

Permits for incineration at sea are evaluated with respect to need on a case-by-case basis, with the unavailability of alternative capacity on land being the major criterion. Wastes to be incinerated at sea are prohibited from containing chlorinated dibenzofurans, PCBs or PCTs, dioxins, or DDT. Quantities of waste incinerated at sea have ranged as high as 100,000 mt annually but have gradually decreased since 1980. For example, a reported 41,000 mt of German waste was incinerated at sea in 1983. Nevertheless, the FRG remains the greatest user by far of ocean incineration.

In its response to the OTA survey, the FRG stated its intent to make "every effort to terminate incineration at sea as soon as possible." The FRG anticipates significant decreases in future quantities of waste incinerated at sea, especially for highly chlorinated wastes (those with chlorine content greater than 45 percent), because of completion of a new land-based incinerator in 1987 and greater application of perchlorination and other reuse technologies (17). However, the lack of sufficient land-based capacity precludes the FRG from specifying a date for ending ocean incineration.

The Netherlands

The Netherlands annually generates about 1 million mt of chemical waste, half of which is currently treated or disposed of offsite. Of the waste treated offsite, about 86,000 mt is incinerated on land or at sea. The AKZO treatment facility can incinerate wastes with a high chlorine content (as high as 45 percent; see ref. 17) and regularly receives such wastes from Sweden.

The Netherlands regards "incineration at sea, albeit an environmentally acceptable procedure, as a temporary expedient; land alternatives are to be preferred." Efforts are underway to develop further land-based incineration capacity and make greater use of recycling methods.

A new land-based incinerator is scheduled to begin operation in 1987. If future policy analysis determines that this land-based incinerator constitutes a practical land-based alternative preferable to ocean incineration, The Netherlands expects a sharp decline in the quantities of waste incinerated at sea (17).

The Netherlands has played a central role in much of the testing of the *Vulcanus* ships that has occurred to date; as a result of these studies, it believes that all international requirements are generally being satisfied. As described previously, The Netherlands plans to conduct an ocean incineration research burn of PCB-containing wastes in late 1986 or early 1987, motivated by the loss of land-based incineration capacity in the United Kingdom and France (10,18).

Norway

Norway estimates that it annually generates about 120,000 mt of hazardous waste, 75 percent of which is used oil or oily wastes. Norway uses a large-capacity cement kiln for destroying significant quantities of incinerable liquids and sludges.

Tar wastes from vinyl chloride production, amounting to some 8,000 mt annually, are currently incinerated at sea. To provide an alternative, Norway is considering the construction of a land-based incinerator equipped to reclaim hydrogen chloride.

Norway's official position is that ocean incineration should be terminated as soon as possible. Although its use of incineration at sea has gradually increased, Norway anticipates gradually reducing its use over the next 5 years, as sufficient land-based incineration capacity and recycling technologies are developed.

Sweden

Sweden estimates that a total of 482,000 mt of hazardous waste was generated in 1978. About half of this quantity was treated or disposed of at the site of generation. Most of Sweden's waste that is sent offsite is treated by the State-owned waste treatment network (SAKAB) or by 1 of about 20 other government-licensed waste treatment companies. SAKAB has recently completed a new hazardous waste treatment facility, which uses a large-capacity rotary kiln incinerator, but which cannot handle highly chlorinated wastes.

Sweden has taken a generally restrictive position in international discussions on ocean incineration, stating that it "will accept incineration at sea as a last resort during a transition period," if no land-based treatment alternatives exist. A Swedish law dating from 1971 prohibits dumping or ocean incineration from Swedish ports or Swedish vessels. However, Sweden has used incineration at sea on foreign vessels to a limited extent in recent years: 6,420 mt of organohalogen wastes of Swedish origin were incinerated at sea in 1982. No applications have been approved for such activity since 1983.

Sweden regards land-based incineration as the most practical and preferable alternative to ocean incineration. However, the lack of sufficient capacity, especially to process chlorinated wastes, is cited as a major obstacle to ending Sweden's limited reliance on ocean incineration.

Switzerland

Because of insufficient land-based incineration capacity within Switzerland, about 10,000 mt of organic wastes are exported for incineration. Those wastes with a high (greater than 15 percent) chlorine content are, without exception, sent for incineration at sea. This quantity averages about 5,000 mt annually and has been increasing over the last several years. Switzerland expects that the quantities of waste it incinerates at sea will continue to increase at least in the short term, because of stricter controls over land disposal and the length of time required to develop land-based capacity. For the long term, Switzerland regards land-based incineration to be environmentally preferable to ocean incineration because of the greater control the authorities are able to exert on land.

United Kingdom

A total of 3.78 million mt of "hazardous and difficult wastes" are disposed or treated offsite in the United Kingdom each year. An estimated 2 percent (80,000 mt) is incinerated at 11 land-based facilities. The recent closure of one very large land-based incinerator has increased demand for incineration at sea (17).

In 1982, the United Kingdom used incineration at sea for only 852 mt of waste, "which would have presented special problems if incinerated in land-based units." Ocean incineration has been increasingly used since 1981: 2,700 mt in 1983 and 3,500 mt in 1984 were incinerated at sea. The United Kingdom regards ocean incineration of certain wastes to be the best practicable environmental option (5).

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Acronyms and Abbreviations

BA
BH
Bt
CA
CI
CI
CI

CI
CO
CO
CO
CZ
DI
DI
DO
DI
ED
EI
EI
EI

FR
FR
HO
HV

Acronyms and Abbreviations

T	—Best available technology
C	—Benzene hexachloride
	—British thermal unit
A	—Clean Air Act
O	—Congressional Budget Office
	—Combustion efficiency
RCLA	—Comprehensive Environmental Response, Compensation and Liability Act
R	—Code of Federal Regulations
	—Carbon monoxide
$_2$	—Carbon dioxide
TP	—Captain of the Port
M	—Coastal Zone Management
T	—Dichlorodiphenyl trichloroethane
	—Destruction efficiency
T	—Department of Transportation
E	—Destruction and removal efficiency
C	—Ethylene dichloride
C	—European Economic Community
	—Environmental Impact Statement
A	—U.S. Environmental Protection Agency
	—Federal Register
G	—Federal Republic of Germany
l	—Hydrogen chloride
DMS	—Hazardous Waste Data Management System
IM	—Intermodal
IMO	—International Maritime Organization
LDC	—London Dumping Convention
MPRSA	—Marine Protection, Research and Sanctuaries Act
mmt	—Million metric tons
mt	—Metric ton
NMFS	—National Marine Fisheries Service
NOAA	—National Oceanic and Atmospheric Administration
PCB	—Polychlorinated biphenyl
PCT	—Polychlorinated terphenyl
PIC	—Product of incomplete combustion
POHC	—Principal organic hazardous constituent
RCRA	—Resource Conservation and Recovery Act
SAB	—Science Advisory Board
SACSA	—Scientific Advisory Committee for Scientific Advice
SGD	—Scientific Group on Dumping
TCDD	—Tetrachlorodibenzo-p-dioxin
TCDF	—Tetrachlorodibenzofuran
TDE	—Total destruction efficiency
TSCA	—Toxic Substances Control Act
USCG	—United States Coast Guard

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